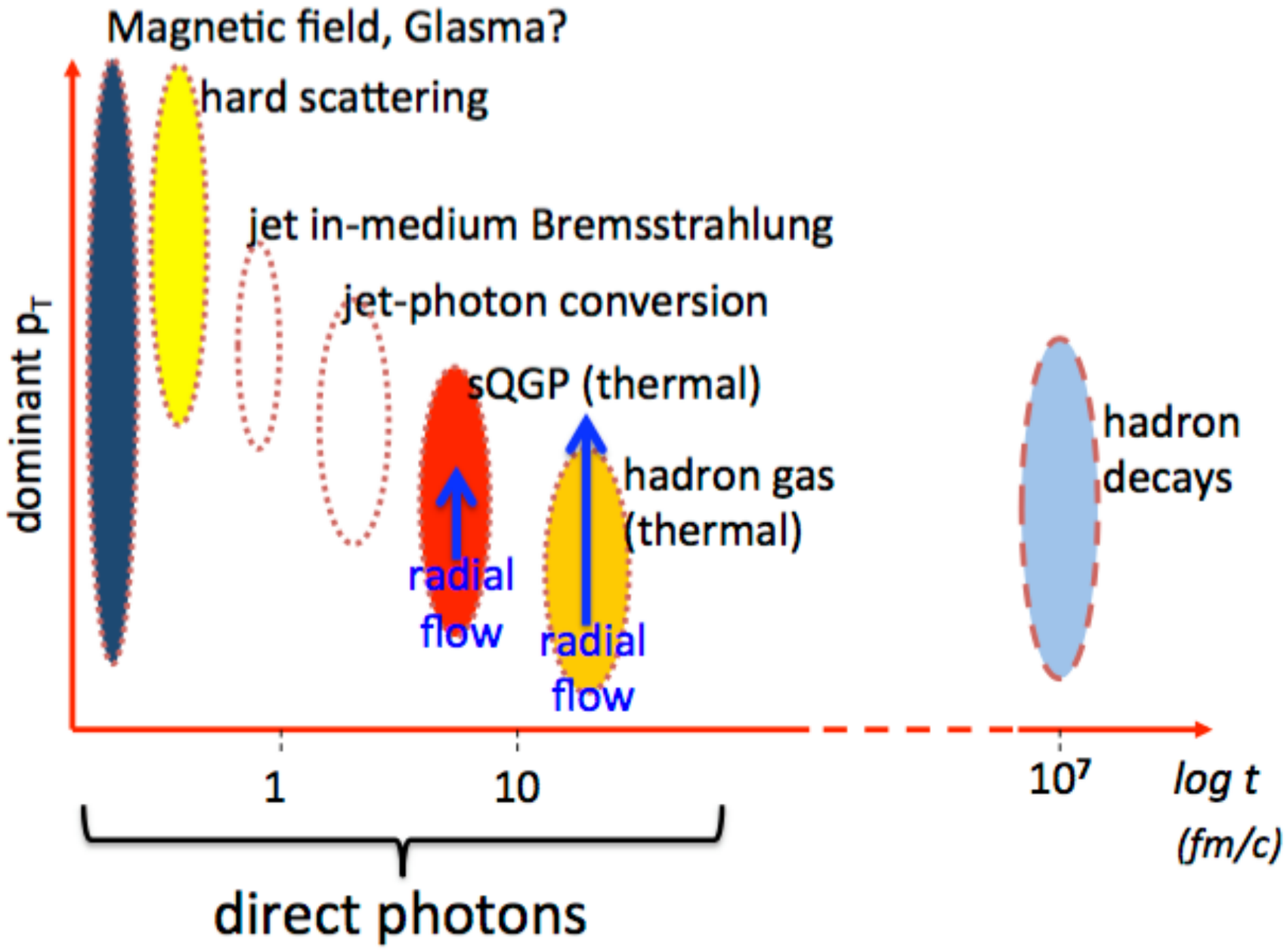
Direct Photon : Beam energy and centrality dependence

Veronica Canoa Roman

Stony Brook University

Direct Photon sources in heavy ion collisions

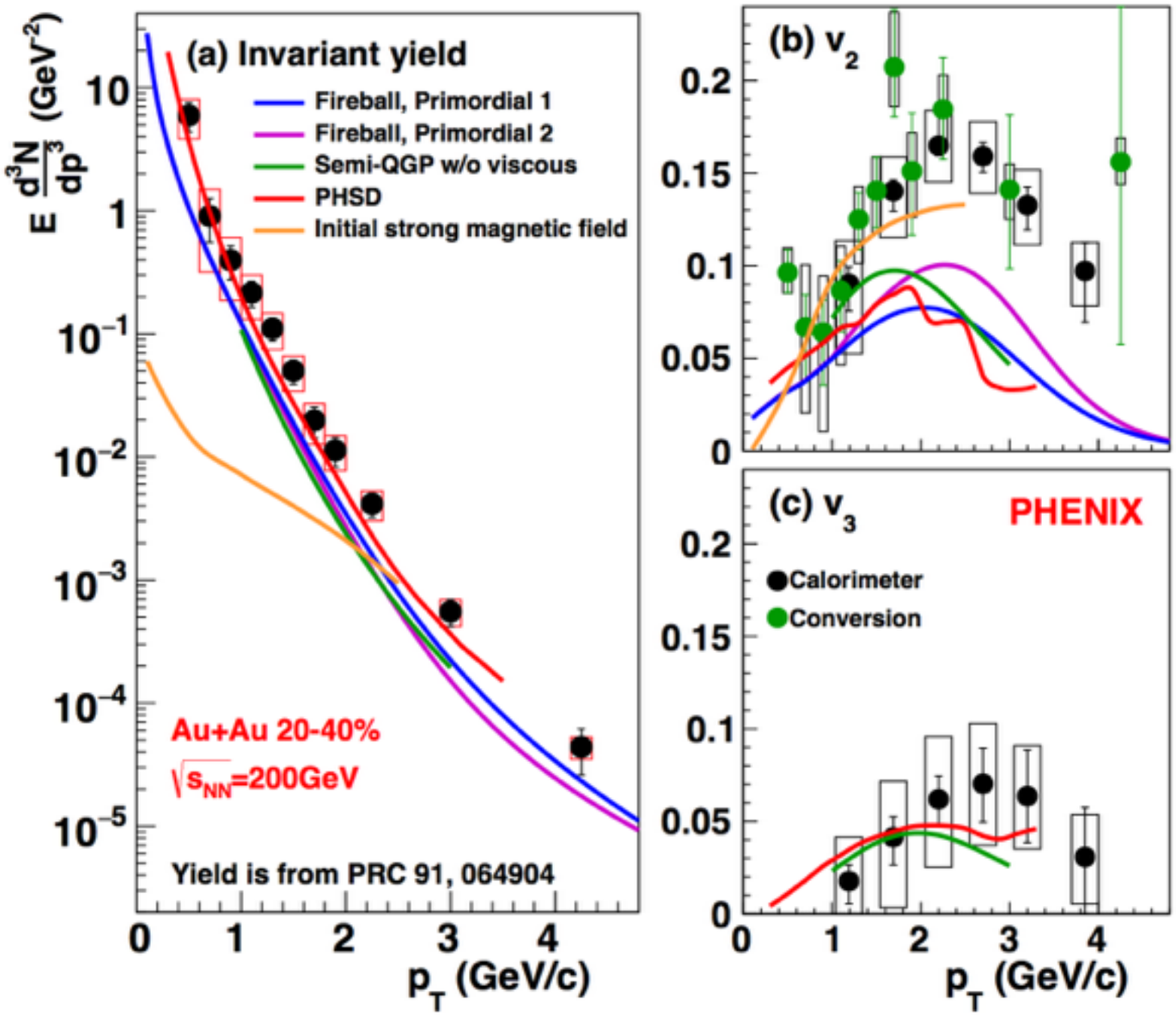


~90 %
π°->γγ
η->γγ

Extracting thermal photon requires the systematic uncertainty of decay photons and prompt photons subtractions less than 10 %

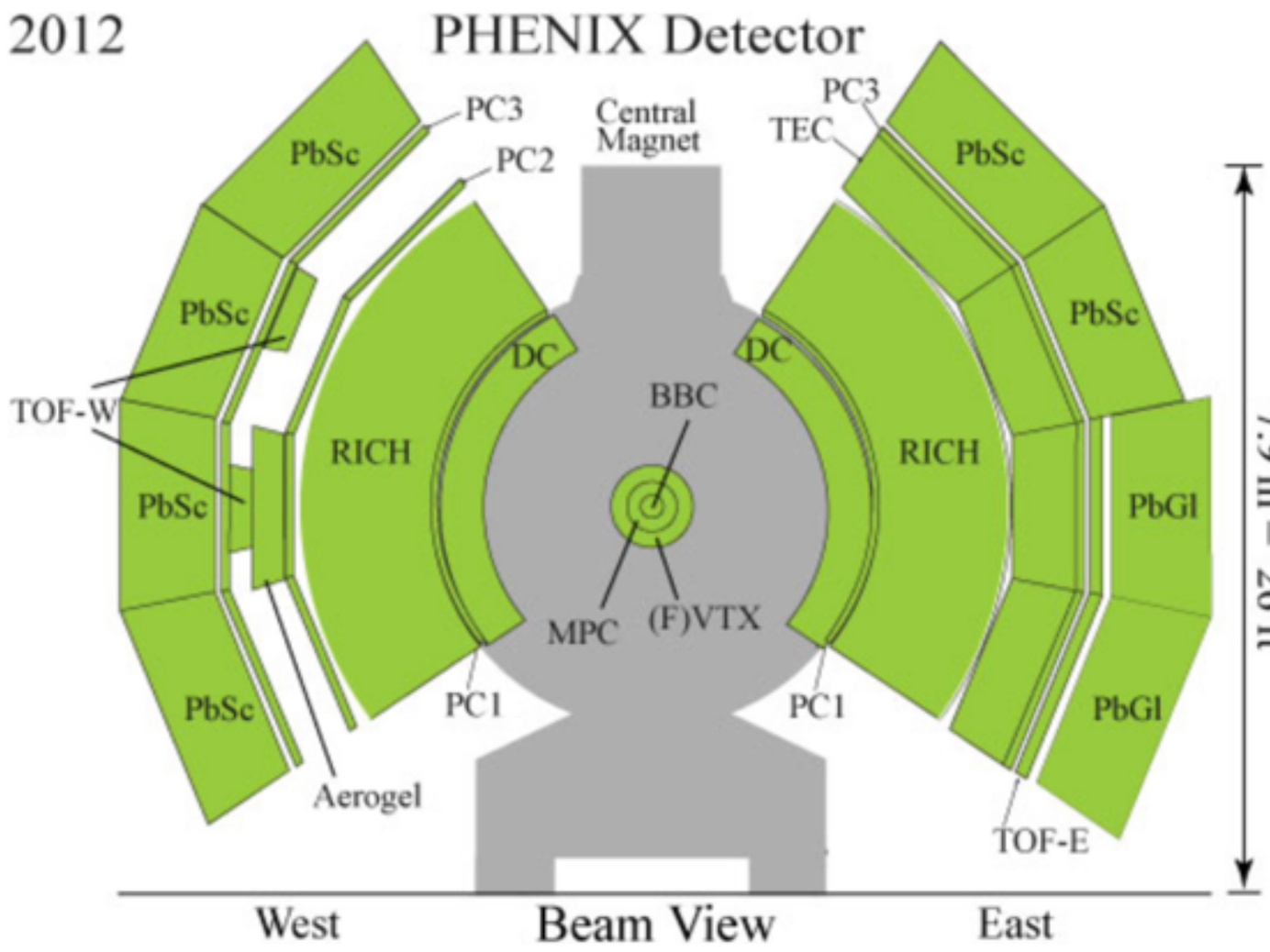
Direct photon challenge

- Large yield and large anisotropy is observed at PHENIX—> challenge to theoretical models:
  - Large yield -> Early emission
  - Large v2 -> Late emission
- In order to understand this, PHENIX has measure data in:
  - Large systems: Au+Au 200, 62, 39 GeV and Cu+Cu at 200 GeV
  - Small systems: p+p, p+Au, d+Au (MB) at 200 GeV



Photon measurement techniques in PHENIX

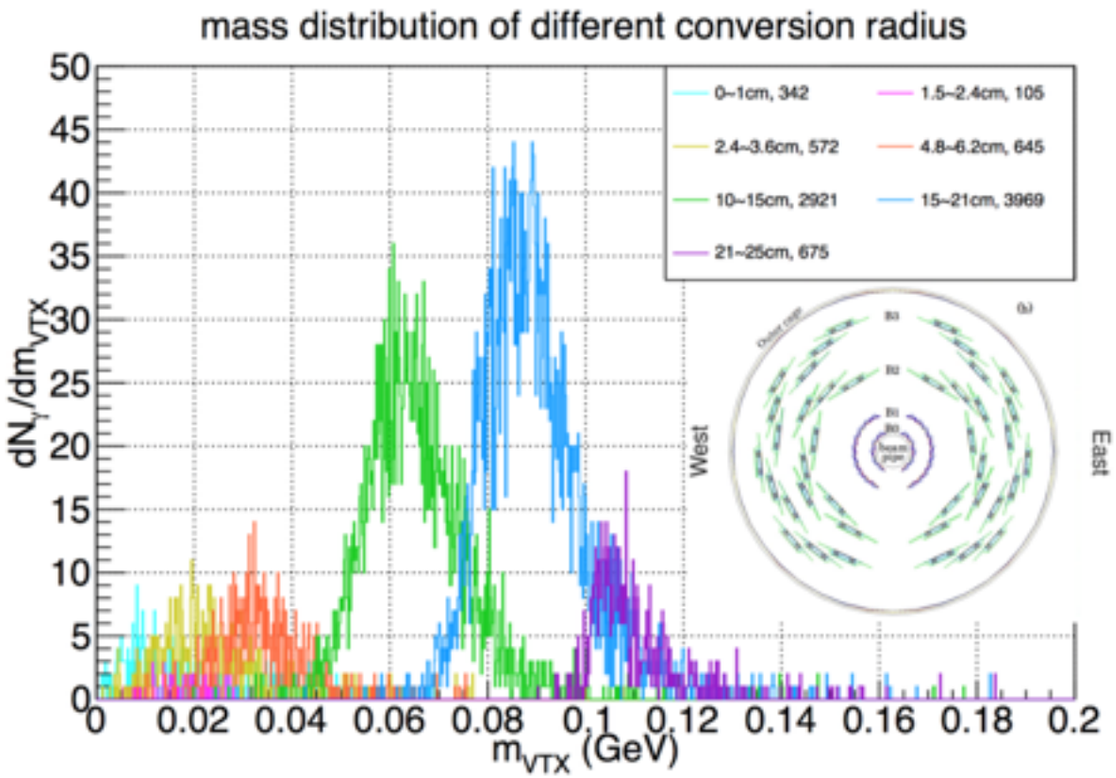
- **Measuring energy deposited by photons in Calorimeter**
  - Good resolution at high pt
  - Low pt contaminated by hadrons
- **Internal photon conversions**
  - Measure virtual photons
  - Reduction in background from hadron decay by a factor of 5
  - Low pt reach is limited(~1 GeV) as well as high pt
- **External conversions**
  - Measure real photons
  - Extends pt<1 GeV and good resolution
  - High pt reach is limited



External conversion method

$\gamma \rightarrow e^+e^-$

- Photon convert in :
  - HBD backplane (~60 cm)(2008- 2010 data).
  - VTX layers (2011- 2016 data)
- Sample purity >98 %
- Double ratio tagging method: cancelation of systematics



$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\left\langle \varepsilon_\gamma f \right\rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

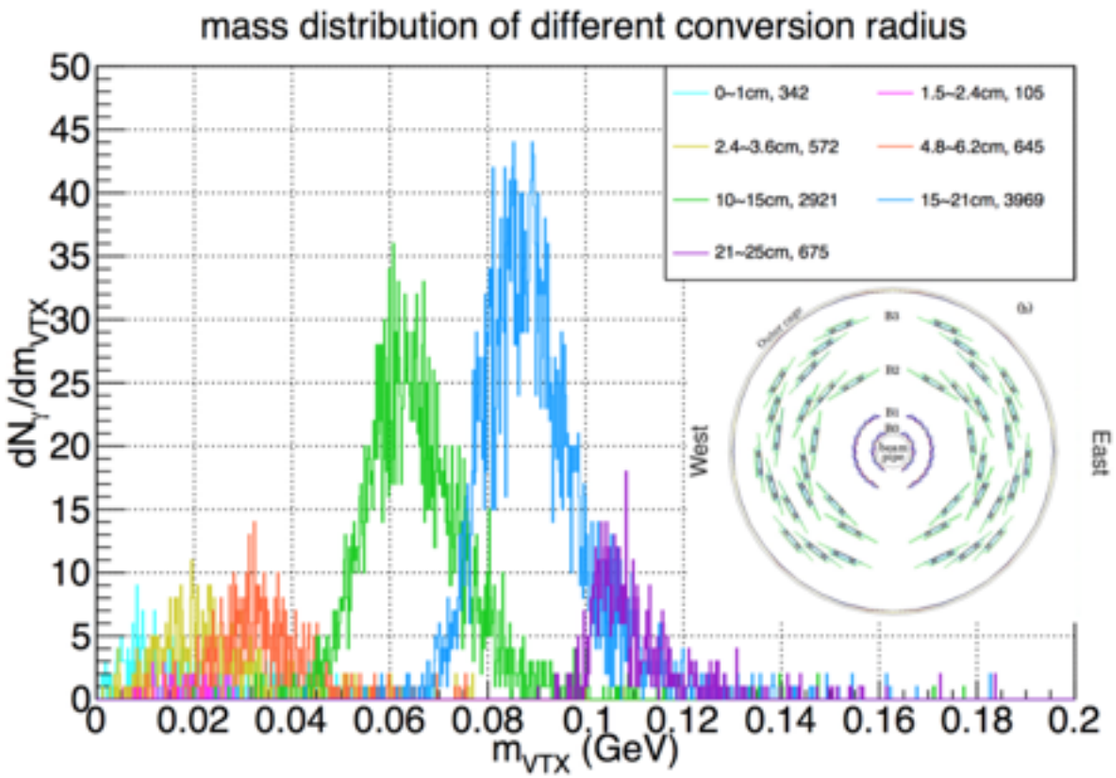
- Measured raw yields
- Conditional tagging efficiency
- Simulated based on hadron data

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

External conversion method

$$\gamma \rightarrow e^+e^-$$

- Photon convert in :
  - HBD backplane (~60 cm)(2008- 2010 data).
  - VTX layers (2011- 2016 data)
- Sample purity >98 %
- Double ratio tagging method: cancelation of systematics



$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\langle \varepsilon_\gamma f \rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

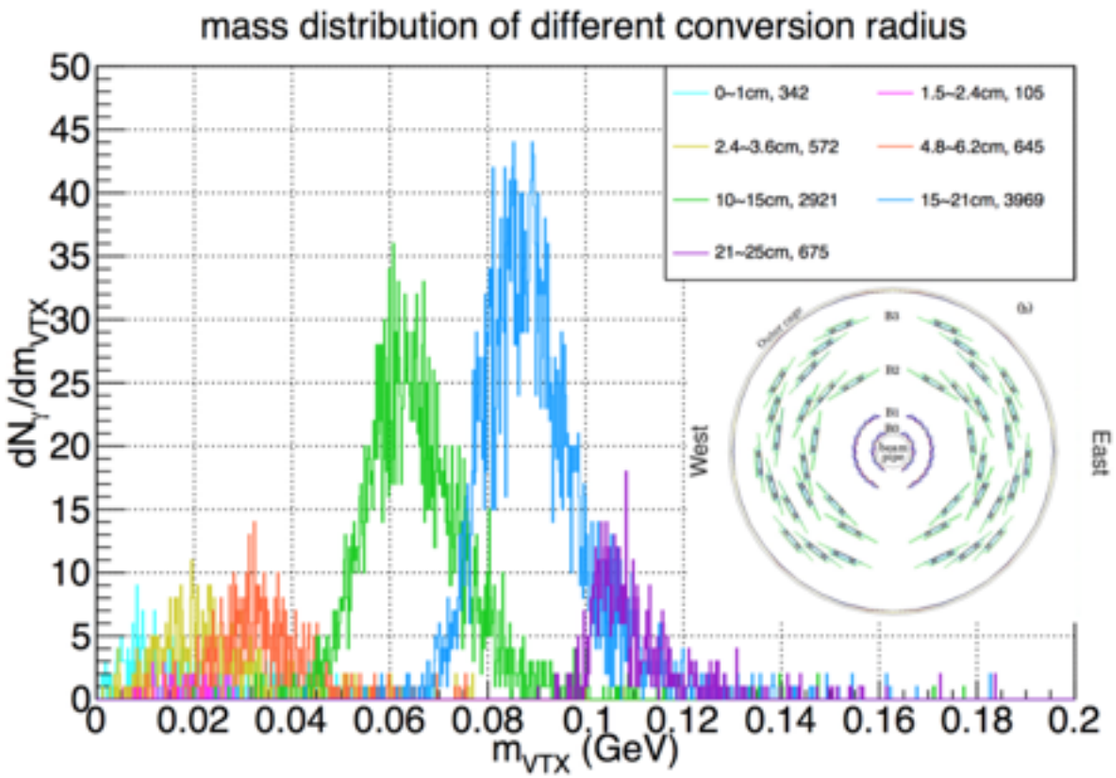
- **Measured raw yields**
- Conditional tagging efficiency
- Simulated based on hadron data

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

External conversion method

$$\gamma \rightarrow e^+e^-$$

- Photon convert in :
  - HBD backplane (~60 cm)(2008- 2010 data).
  - VTX layers (2011- 2016 data)
- Sample purity >98 %
- Double ratio tagging method: cancelation of systematics



$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\left\langle \varepsilon_\gamma f \right\rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

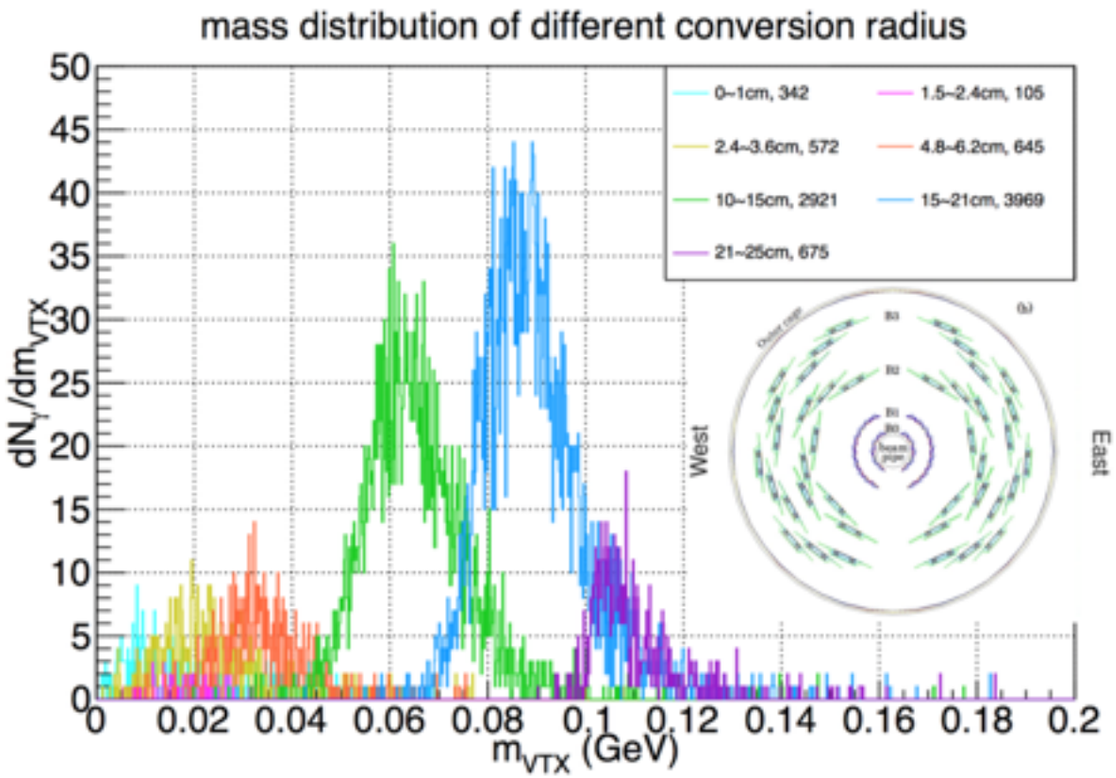
- **Measured raw yields**
- **Conditional tagging efficiency**
- **Simulated based on hadron data**

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

External conversion method

$$\gamma \rightarrow e^+e^-$$

- Photon convert in :
  - HBD backplane (~60 cm)(2008- 2010 data).
  - VTX layers (2011- 2016 data)
- Sample purity >98 %
- Double ratio tagging method: cancelation of systematics



$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\left\langle \varepsilon_\gamma f \right\rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

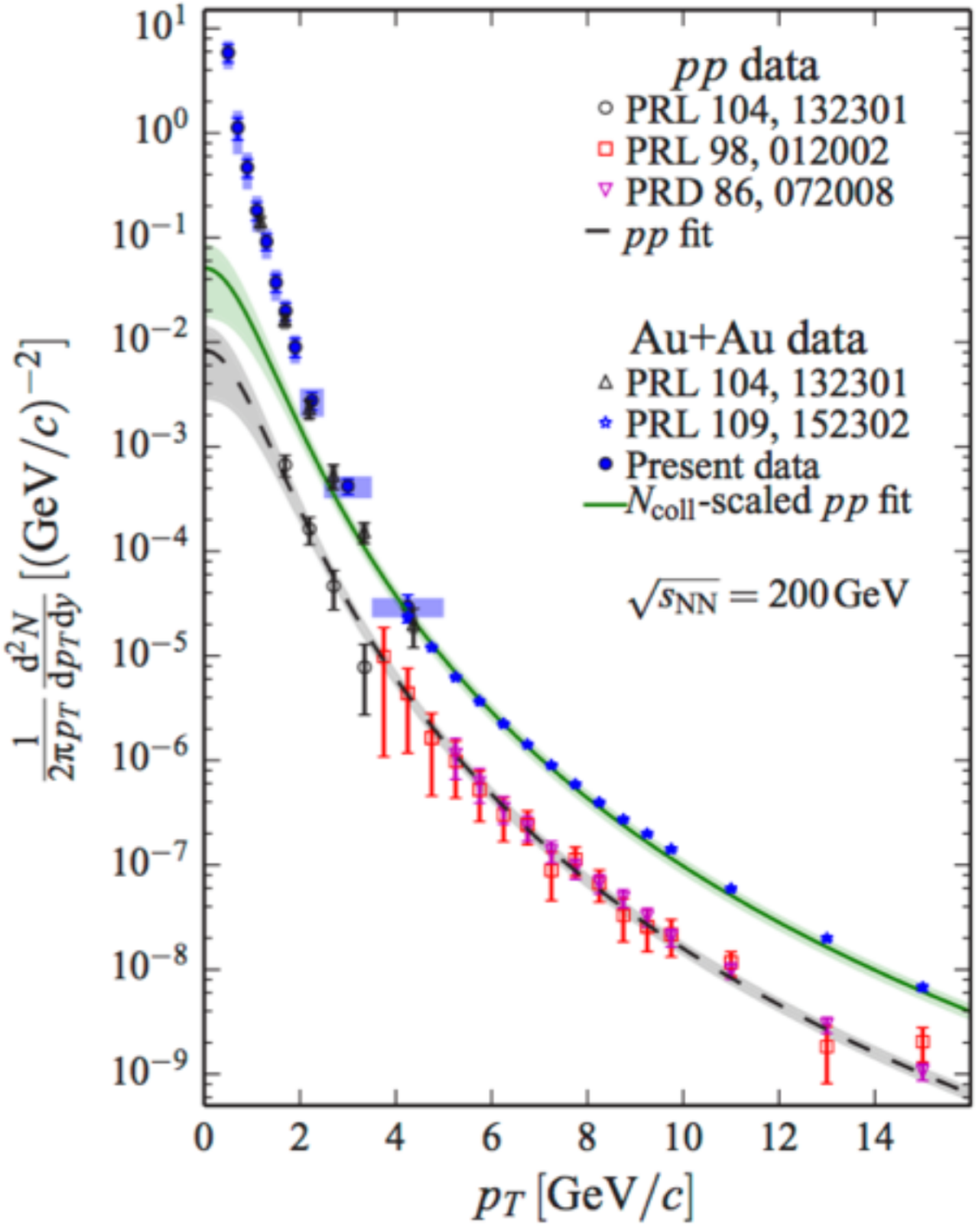
- **Measured raw yields**
- **Conditional tagging efficiency**
- **Simulated based on hadron data**

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

Large systems

Direct photon in Au+Au 200 GeV

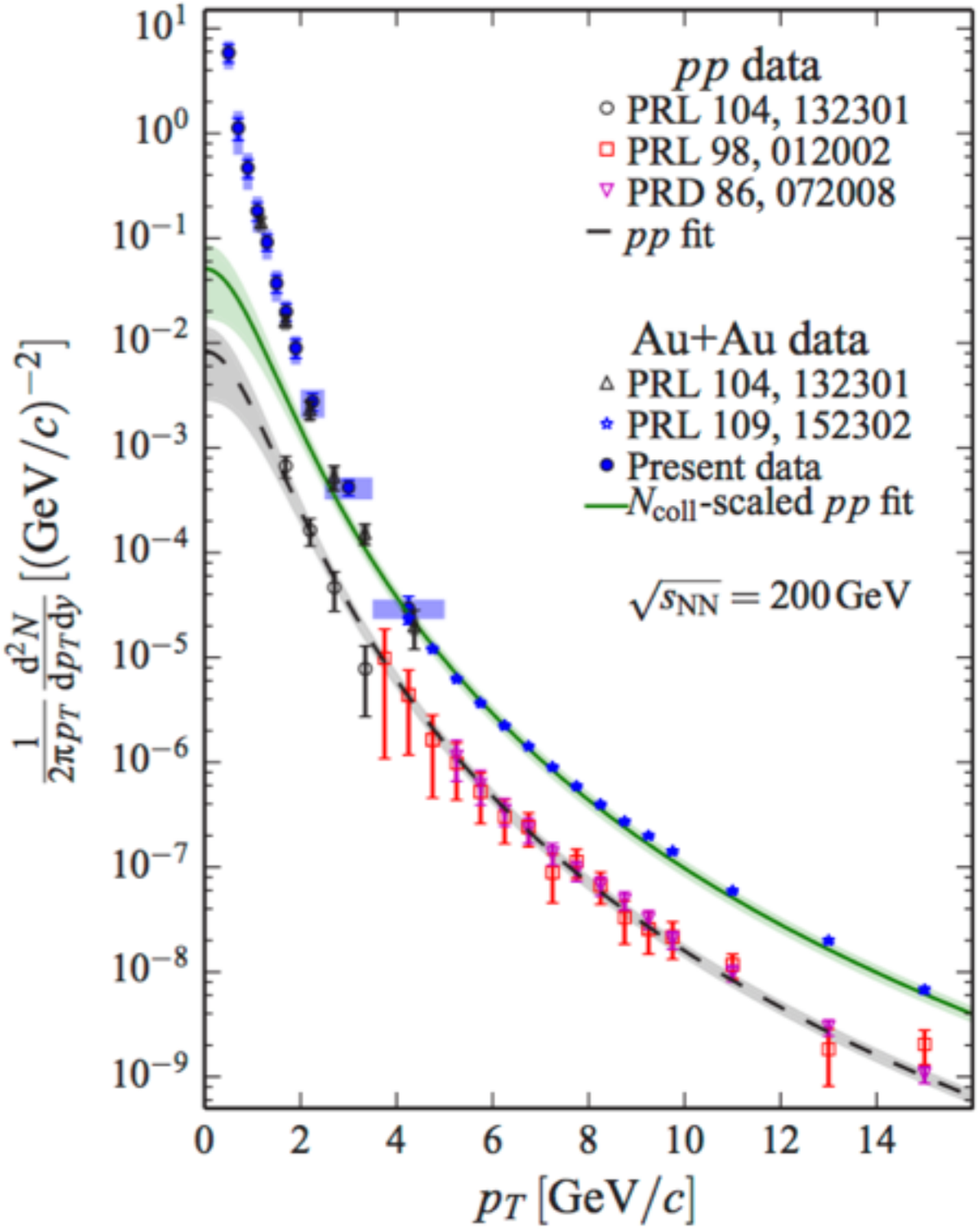
Phys. Rev. C 91 064904(2015)

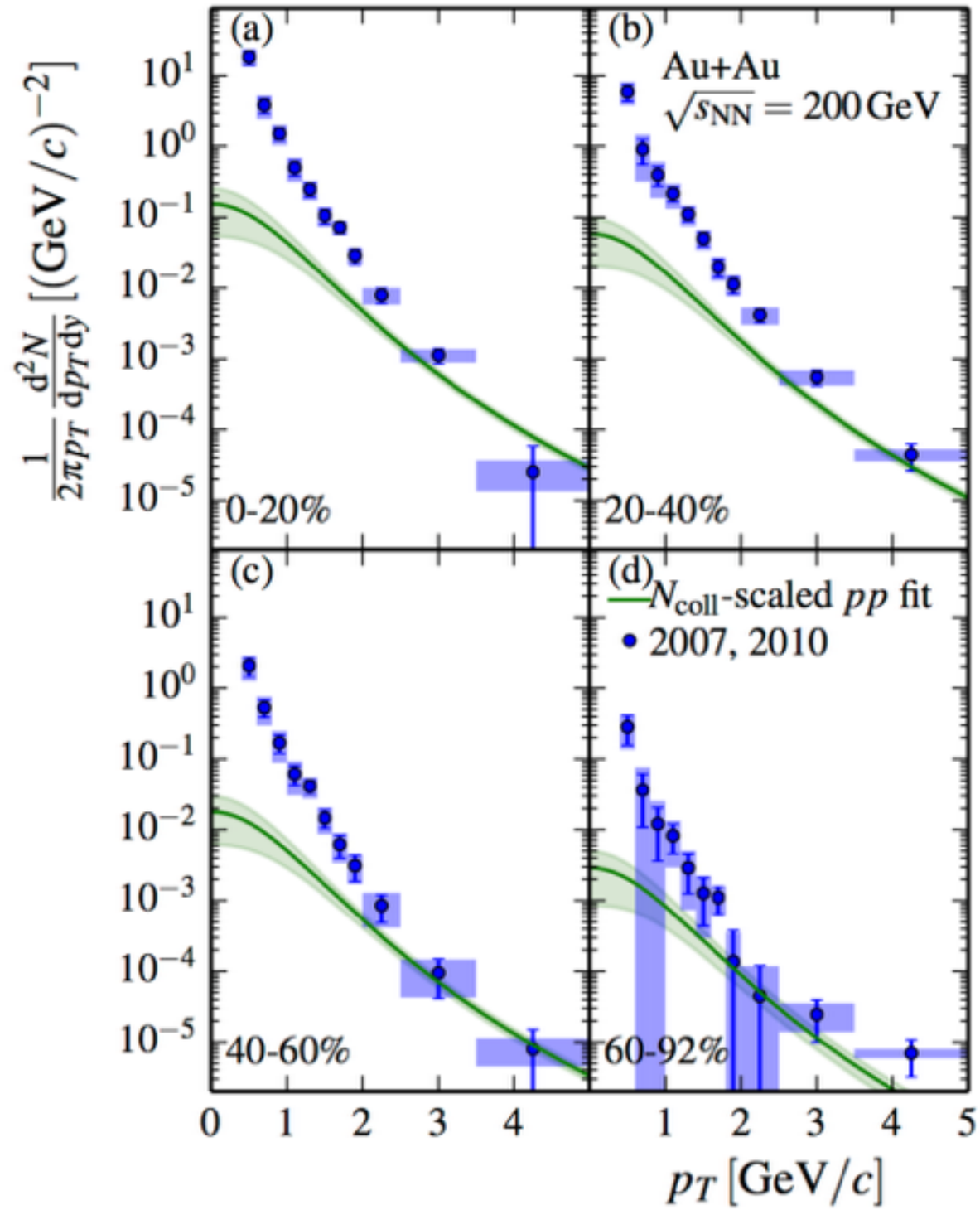


- **Direct photon yield is well established**
  - pp consistent with pQCD
  - AuAu follows Ncoll scaled pp above 4 GeV
  - Significant excess below 3 GeV in Au+Au 200 GeV
  - Excess has nearly exponential shape

Direct photon in Au+Au 200 GeV

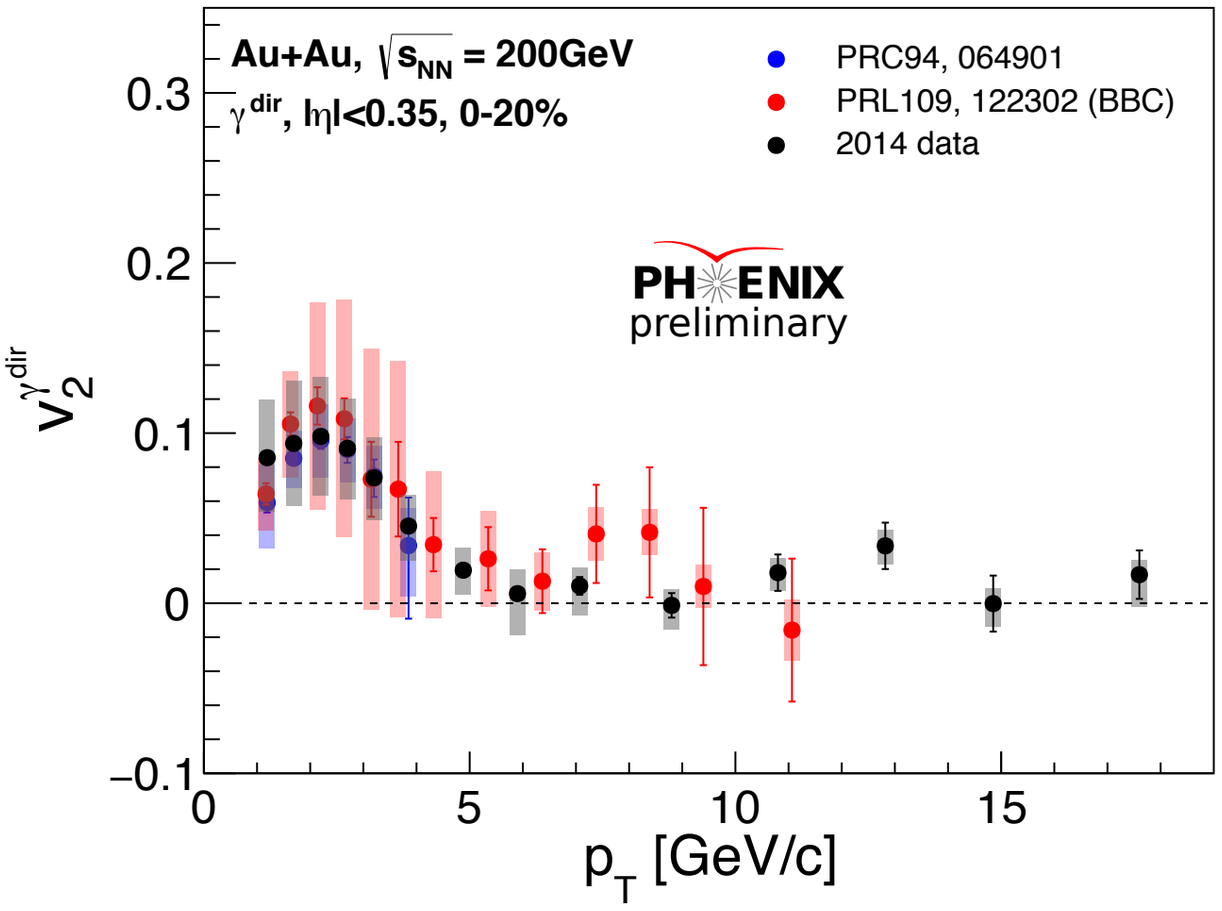
Phys. Rev. C 91 064904(2015)

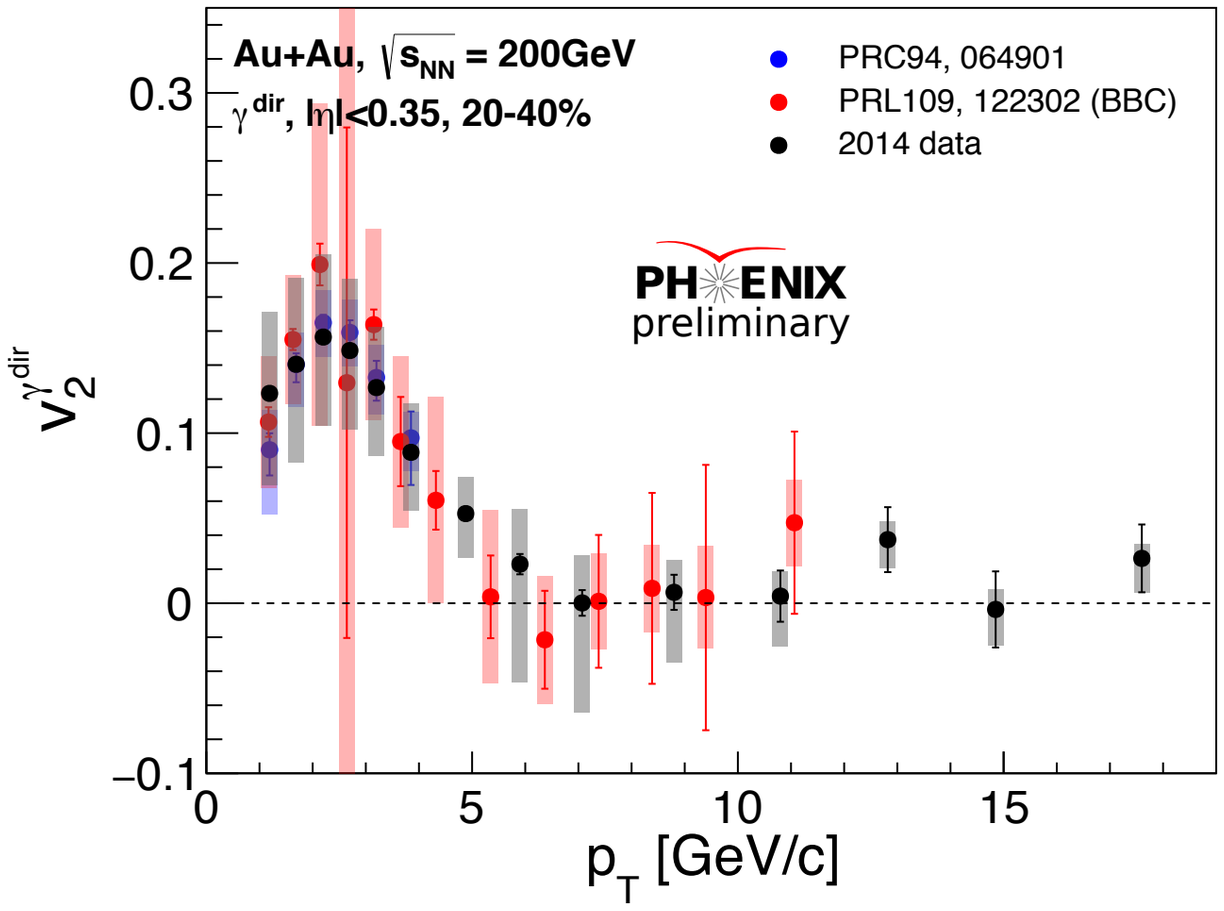




There is no strong centrality dependence in the slope

Update: Direct photon v2 in Au+Au 200 GeV



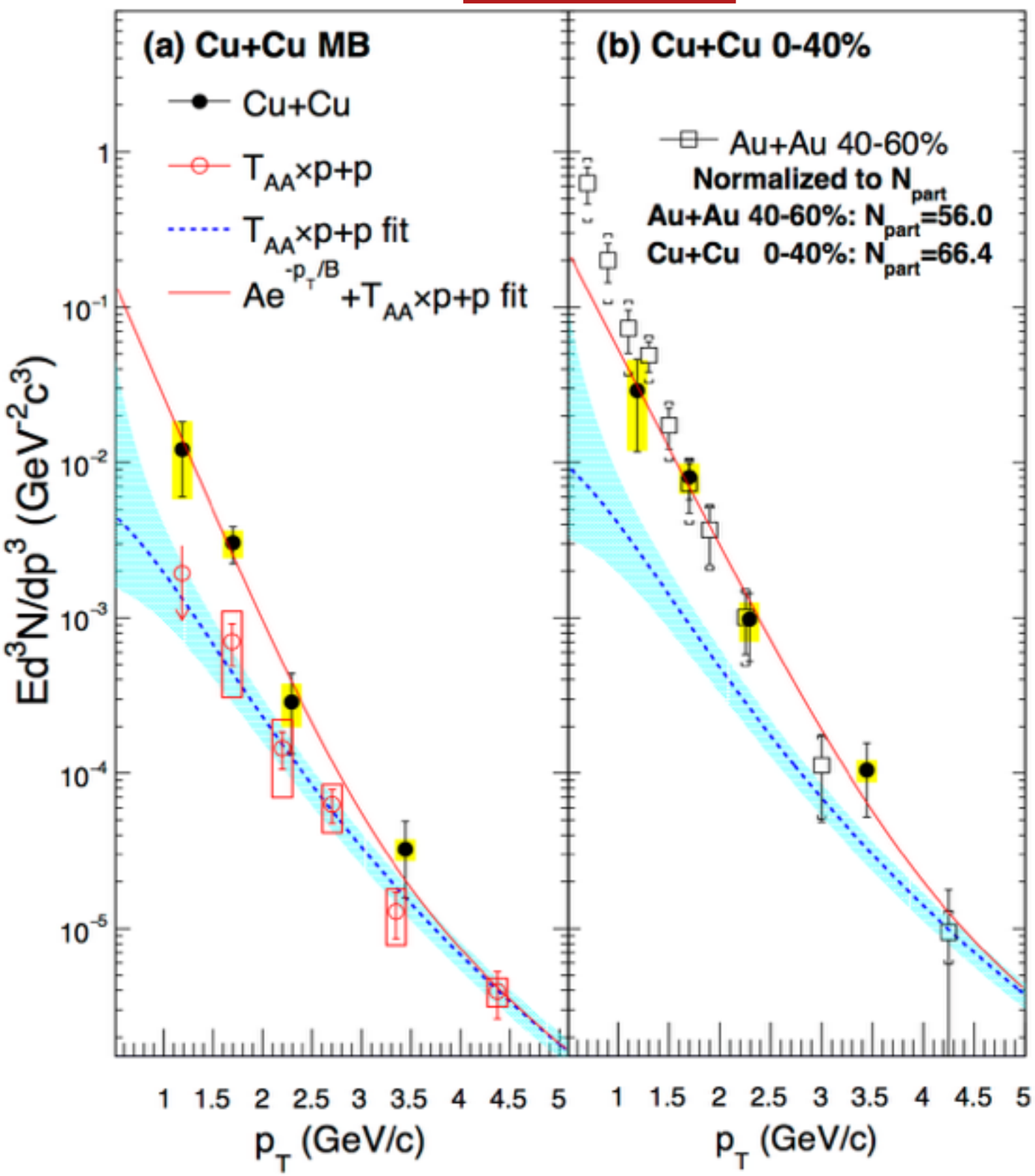


$$v_n^{dir} = \frac{R_\gamma v_n^{inc} - v_n^{dec}}{R_\gamma - 1}$$

- We improved v2 measurement
- v2 high p_T compatible with zero (direct photon source is hard scattering)

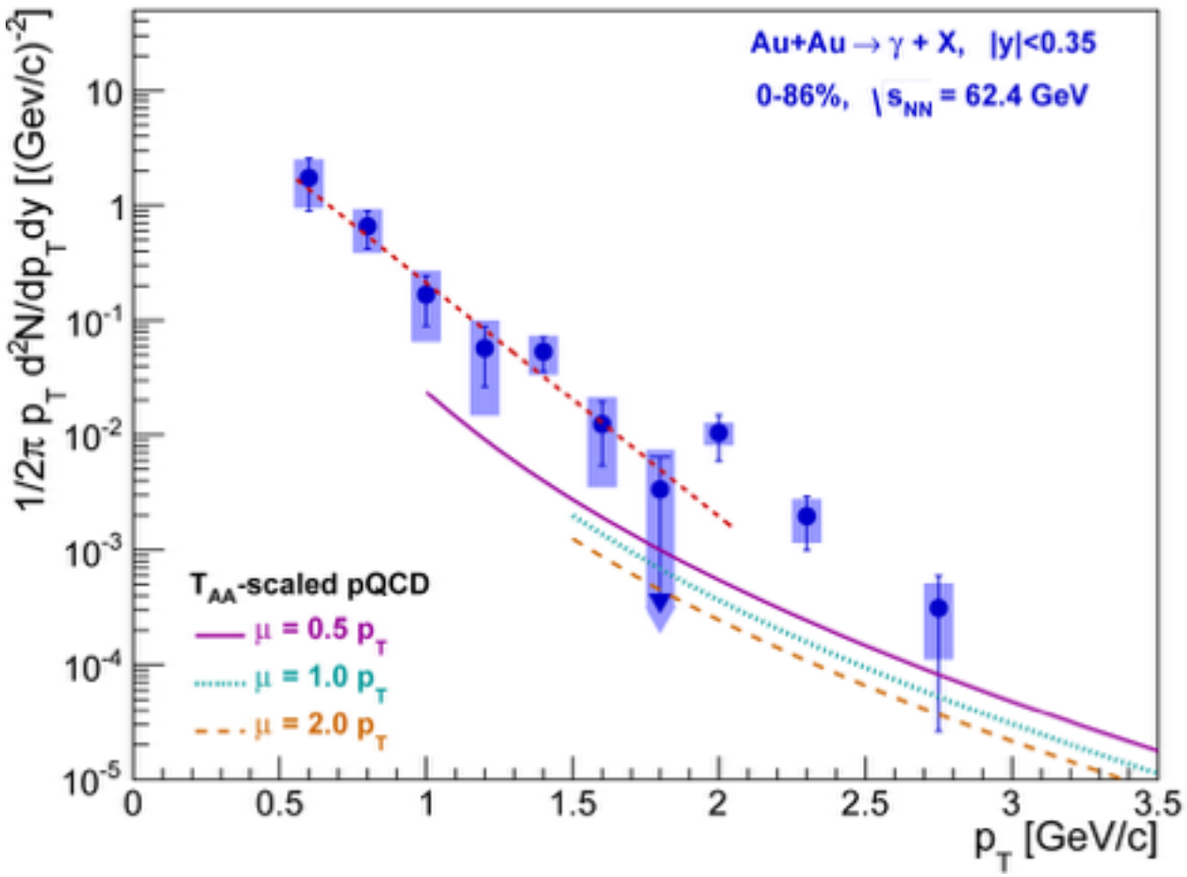
Cu+Cu 200 GeV

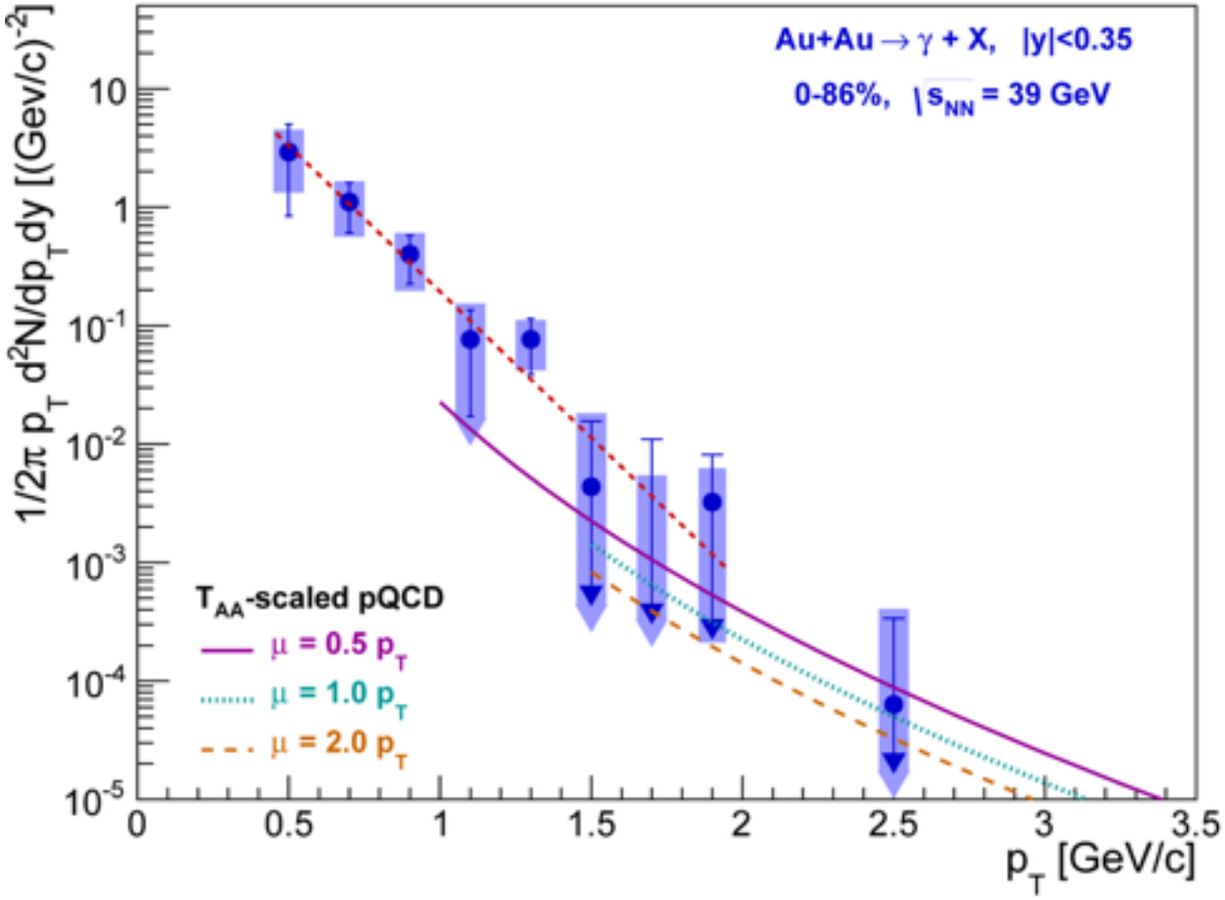
arXiv:1805.04066



*Consistent with Au+Au 200 GeV results at similar Npart

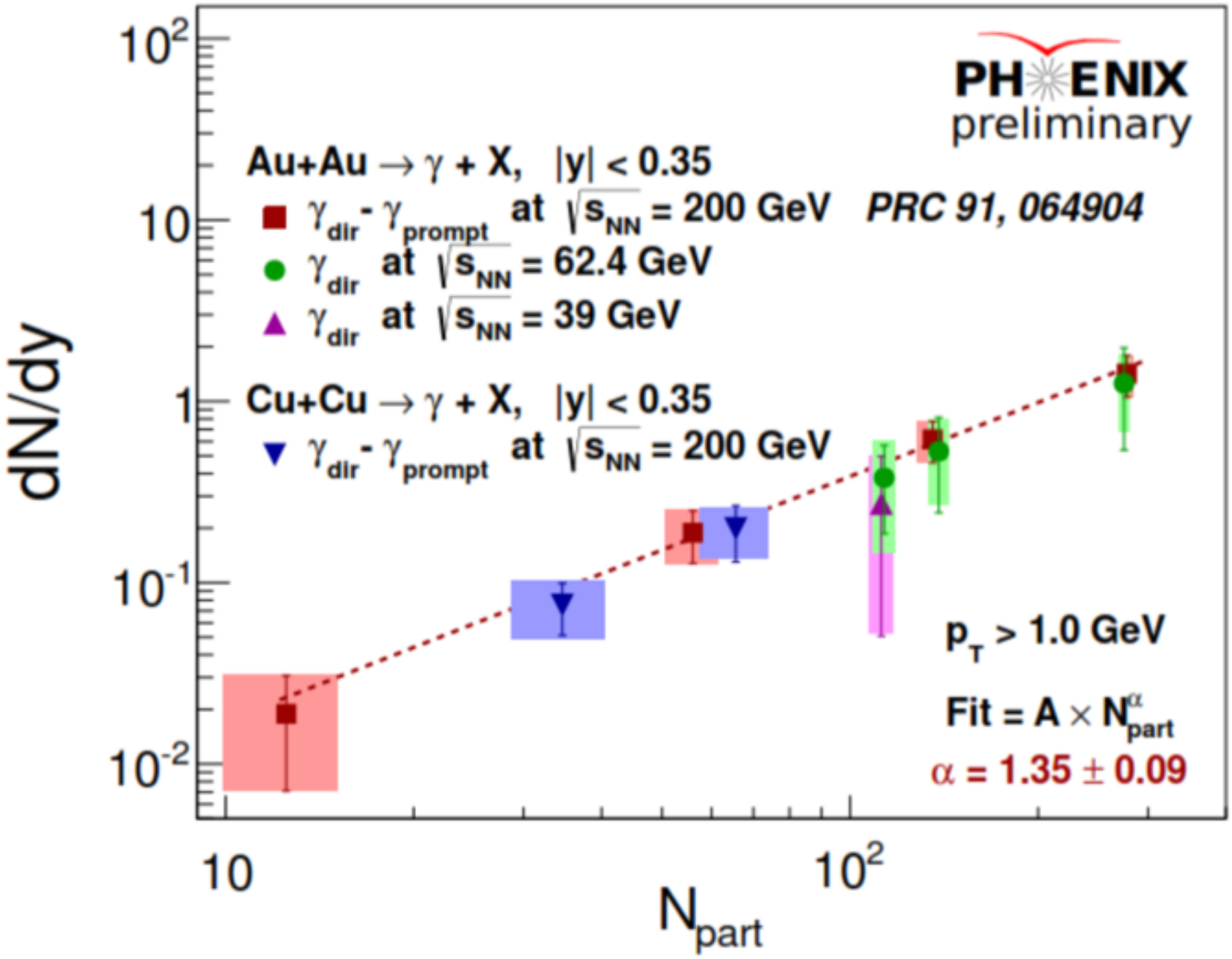
Au+Au 62.4 GeV and 39 GeV





- Clear direct photon signal in Au+Au at 62.4 GeV and 39 GeV

Integrated Yield vs N_{part}

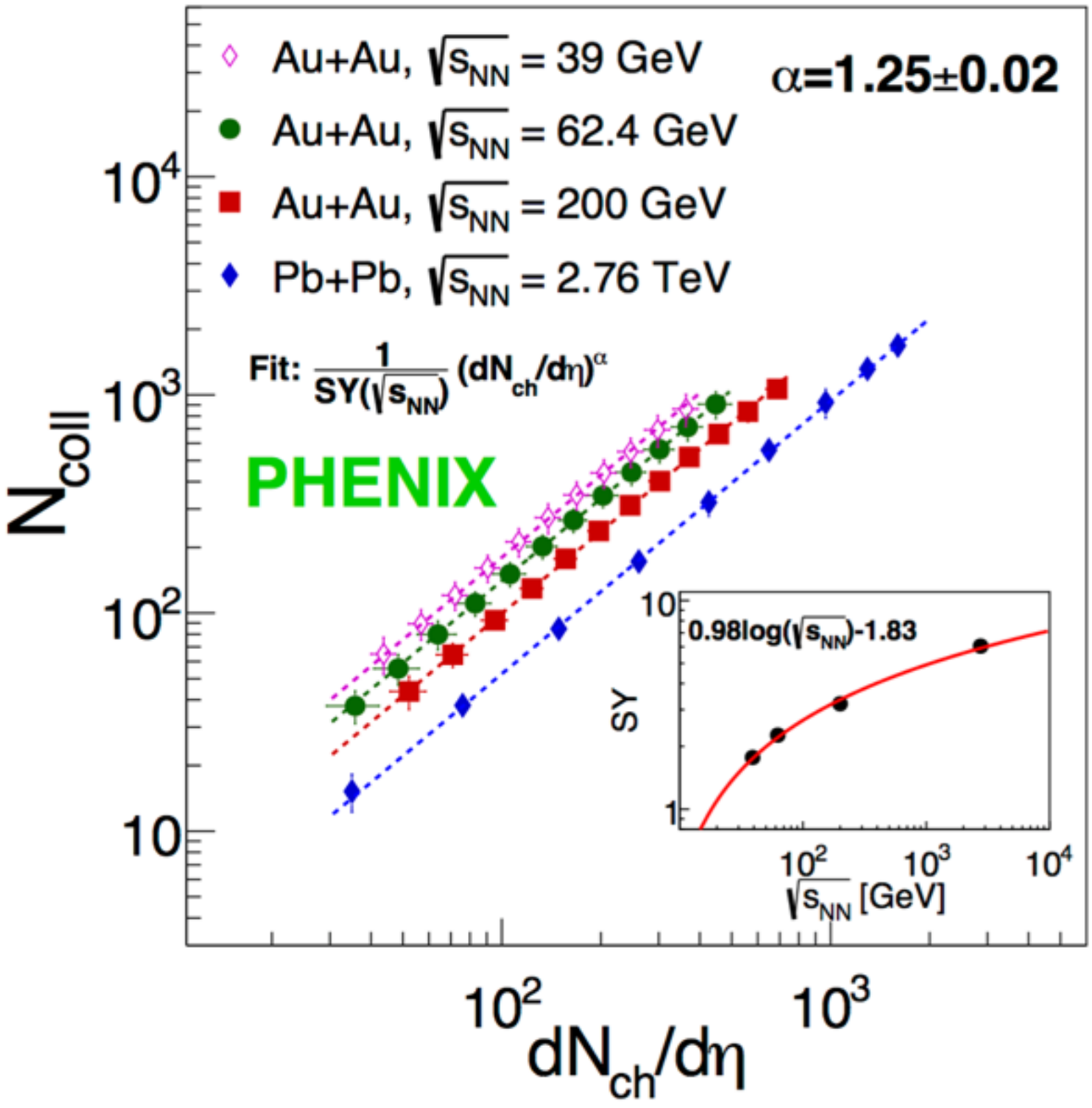


- Similar increase with N_{part} for different systems
- N_{part} saturates at same value for similar size systems at different beam energies

  —> Limitations to compare different collision energies

Interplay between soft and hard scale

arXiv:1805.04084

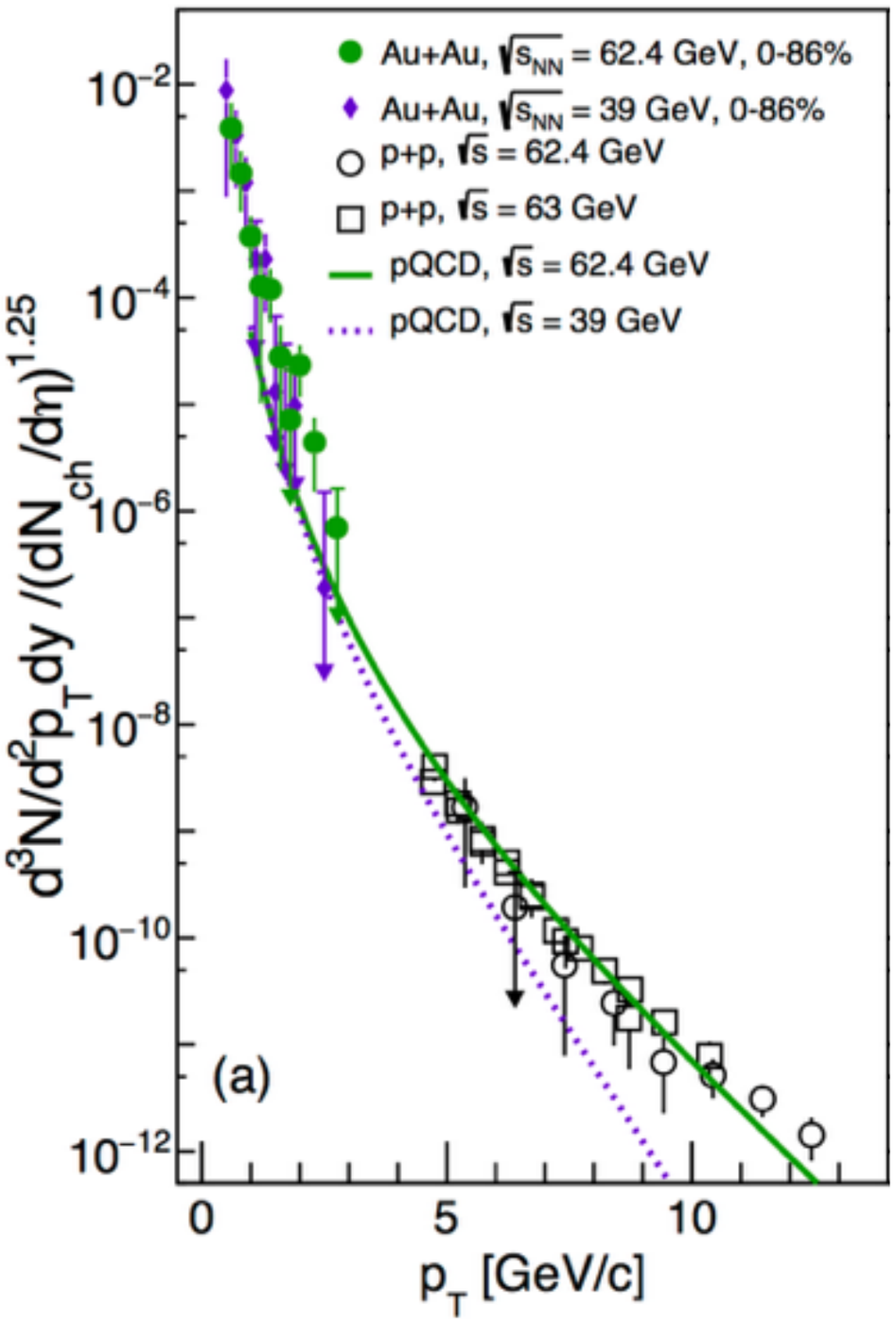


$$N_{coll} = \frac{1}{SY(\sqrt{s_{NN}})}\left(\frac{dN_{ch}}{d\eta}\right)^{\alpha}$$

$$SY\left(\sqrt{s_{NN}}\right) = c_1 \log(\sqrt{s_{NN}}) - c_2$$

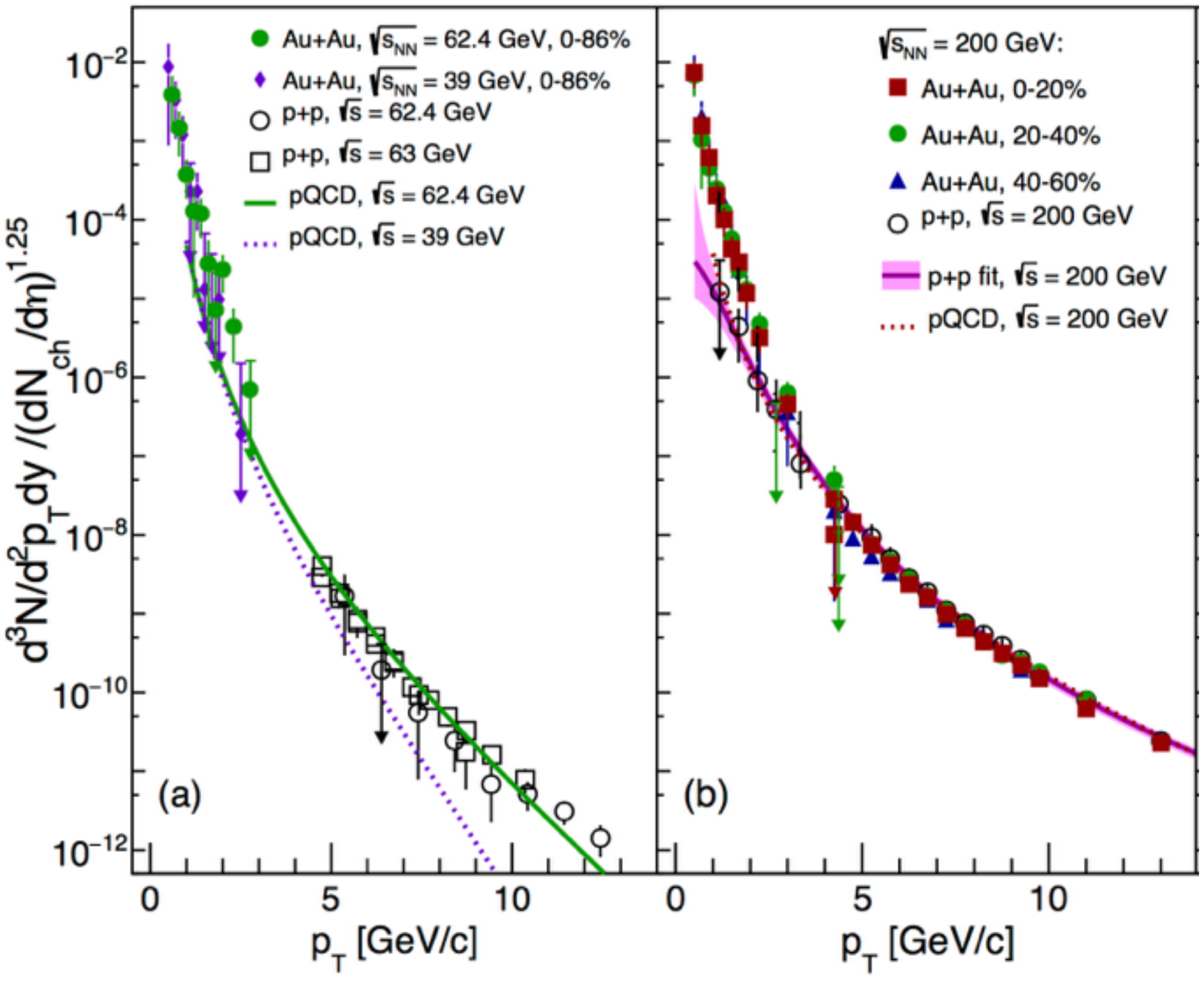
Direct photon scaling

arXiv:1805.04084



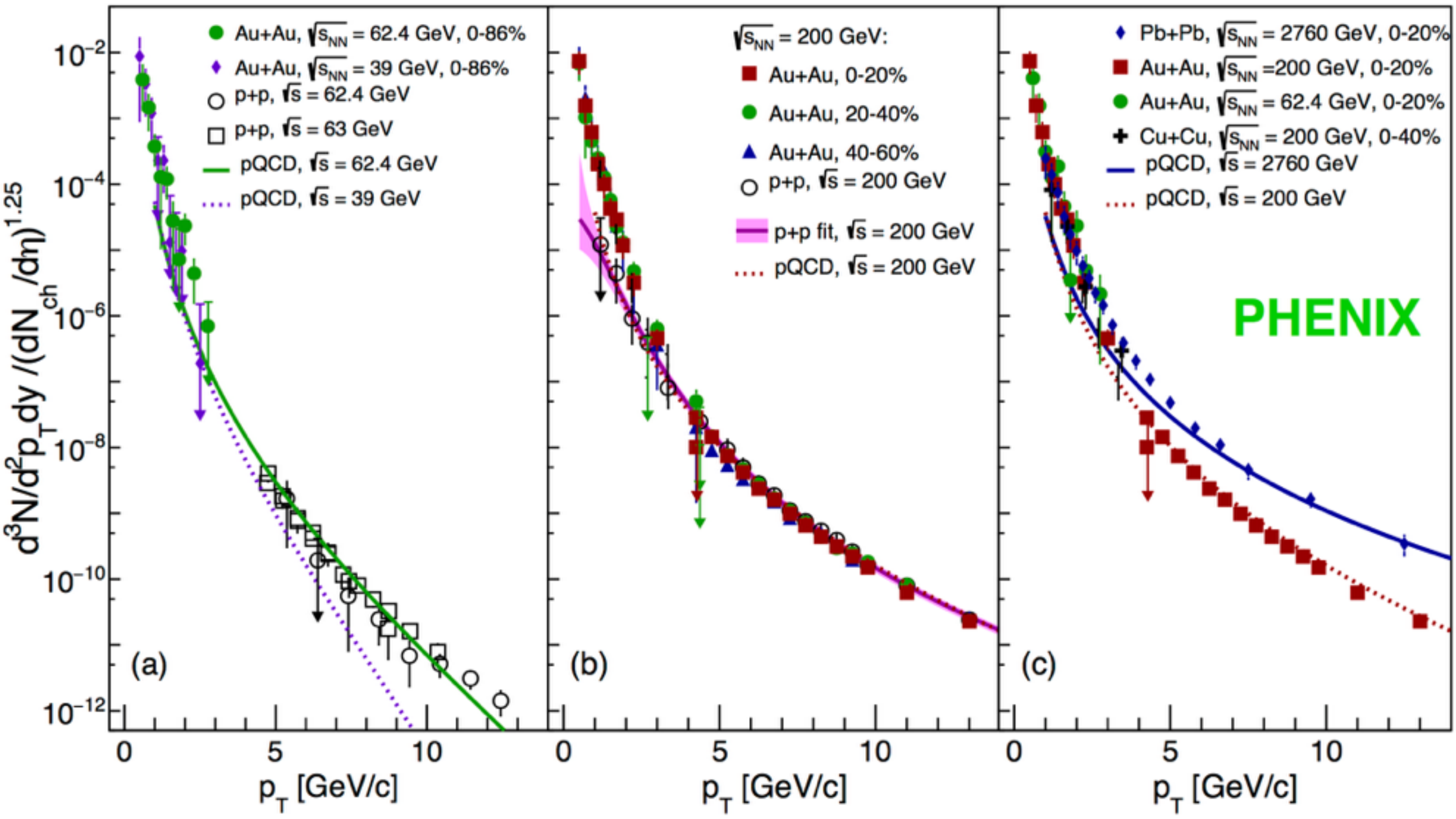
Direct photon scaling

arXiv:1805.04084



Direct photon scaling

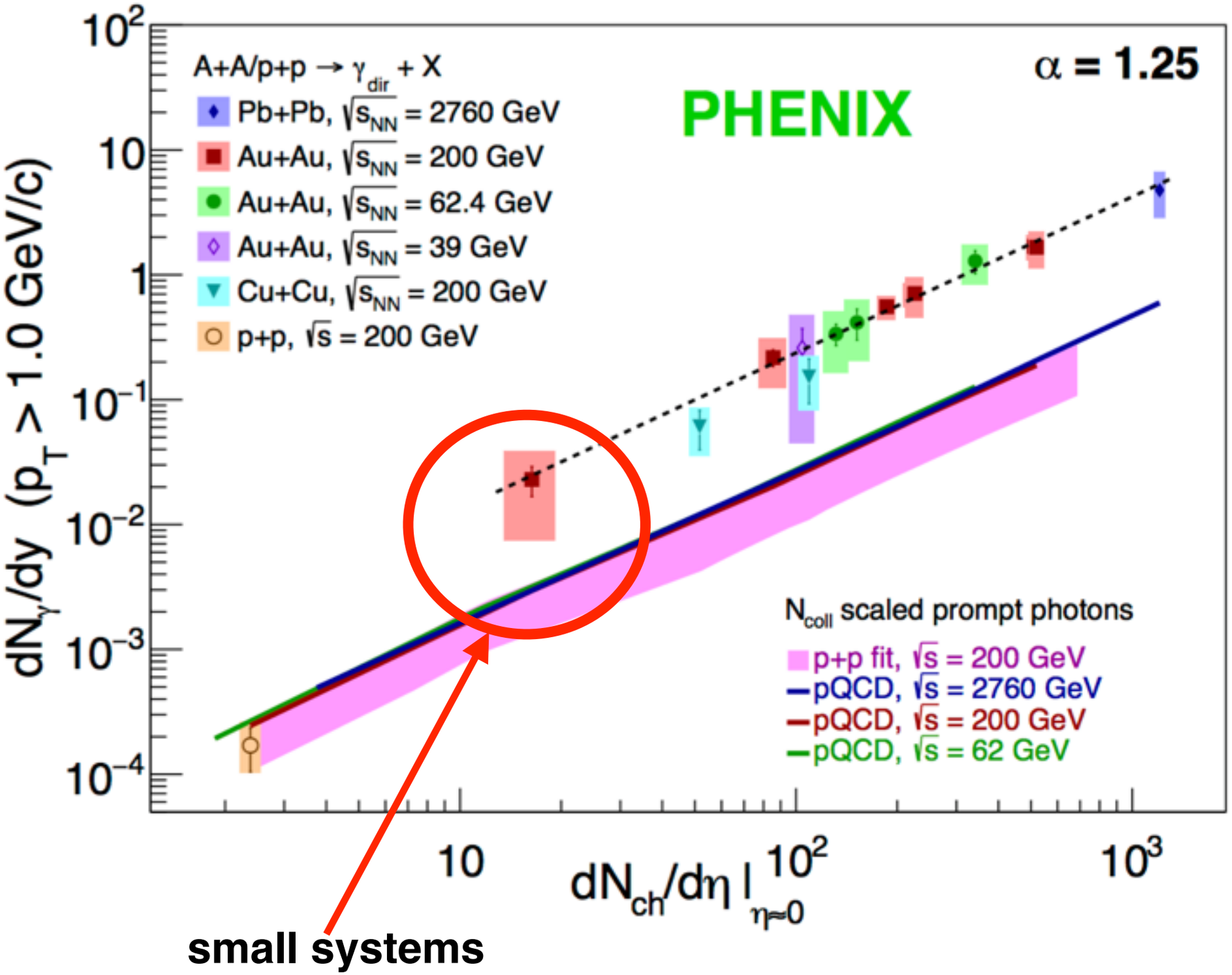
arXiv:1805.04084



Universal behavior at low pT

Direct photon scaling

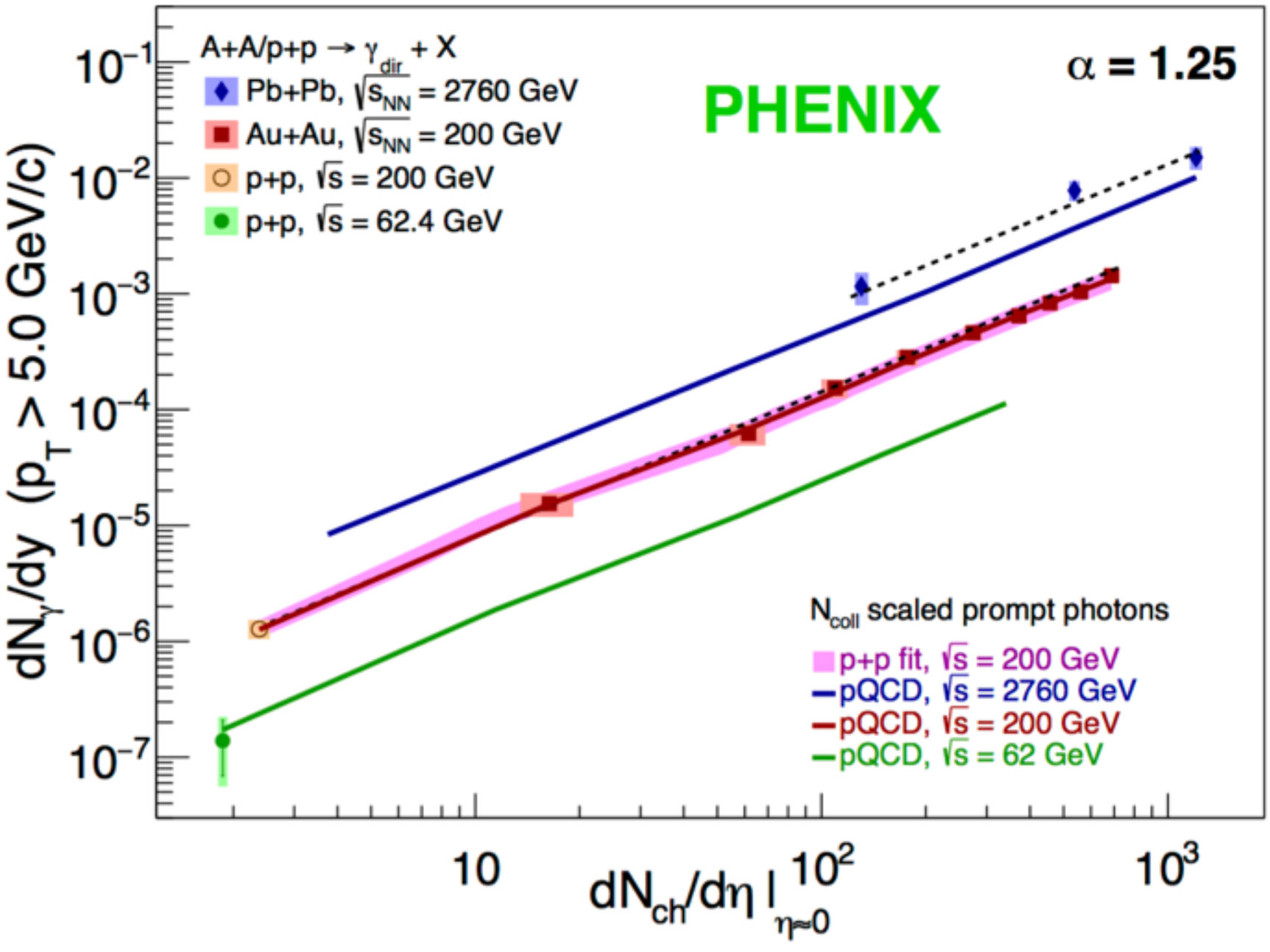
arXiv:1805.04084



small systems

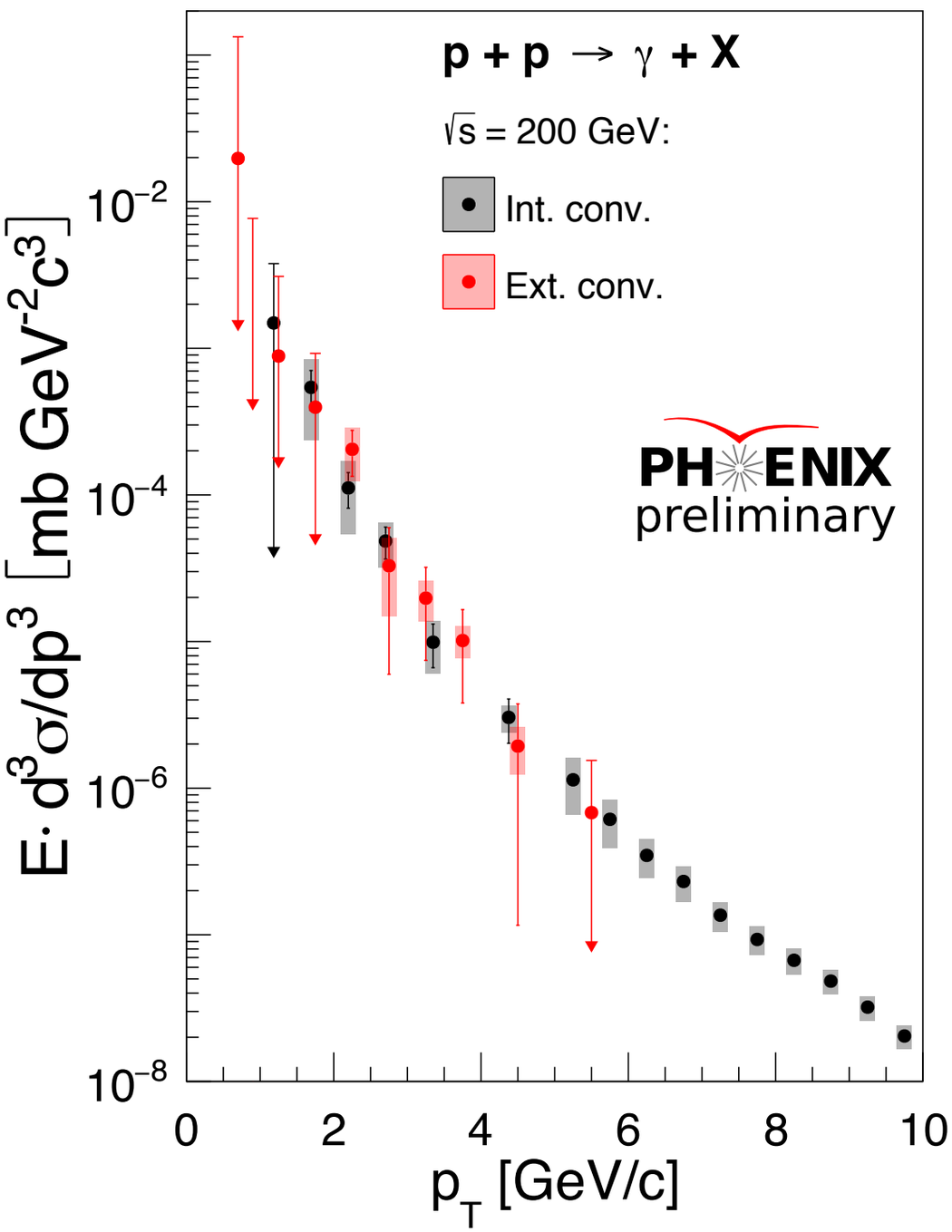
Direct photon scaling

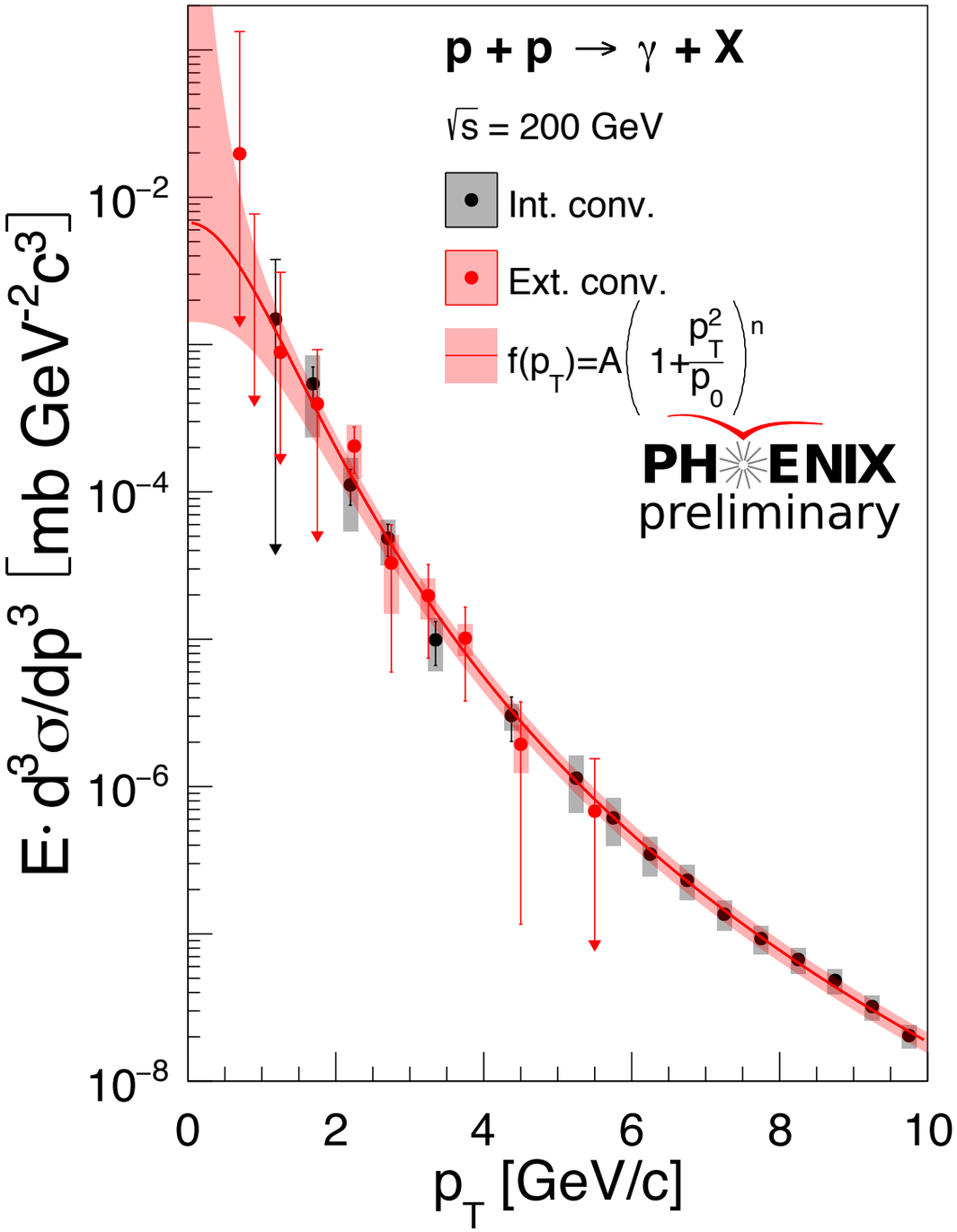
arXiv:1805.04084



Small systems

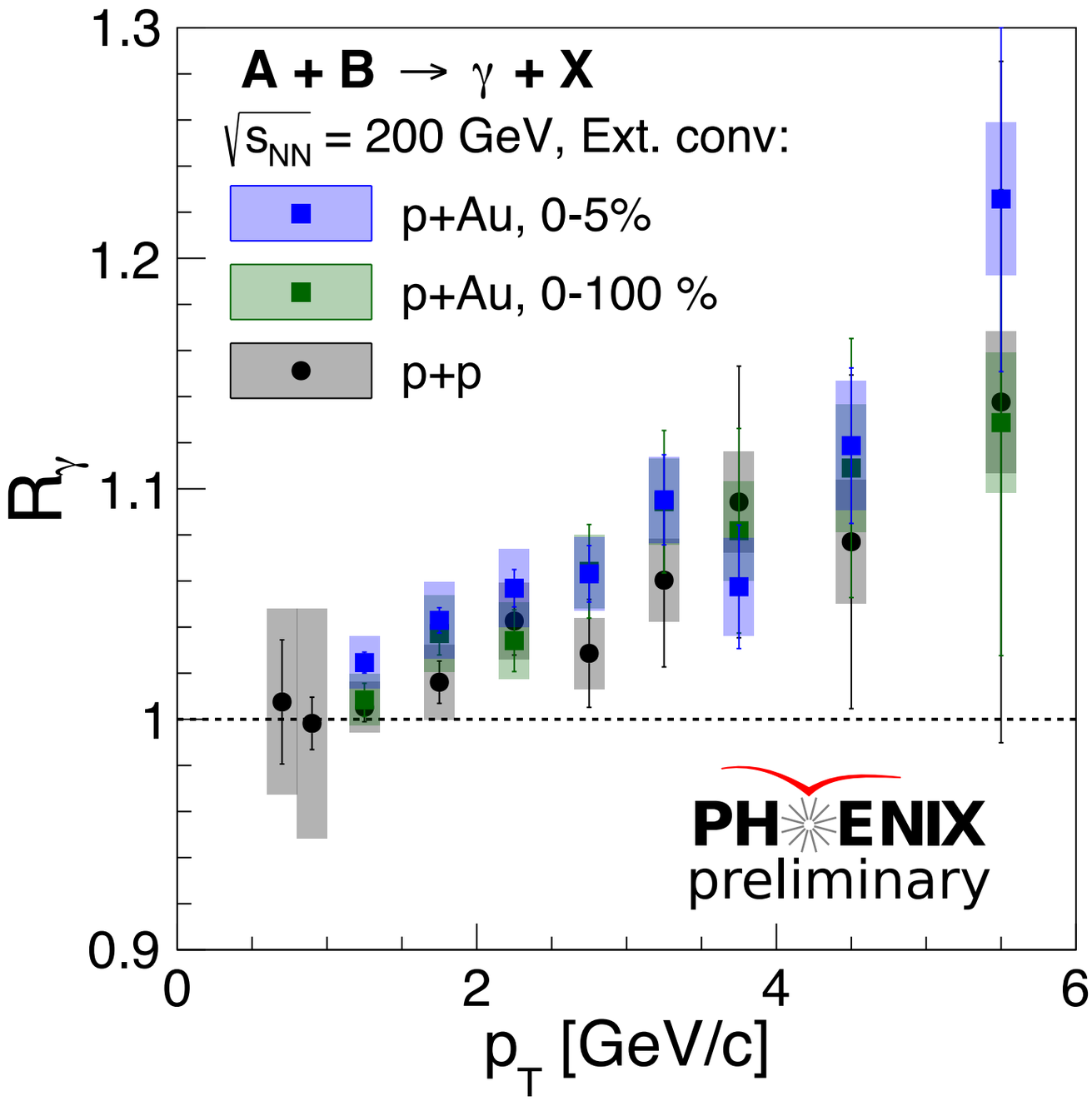
p+p 200 GeV





New fit using three different data sets

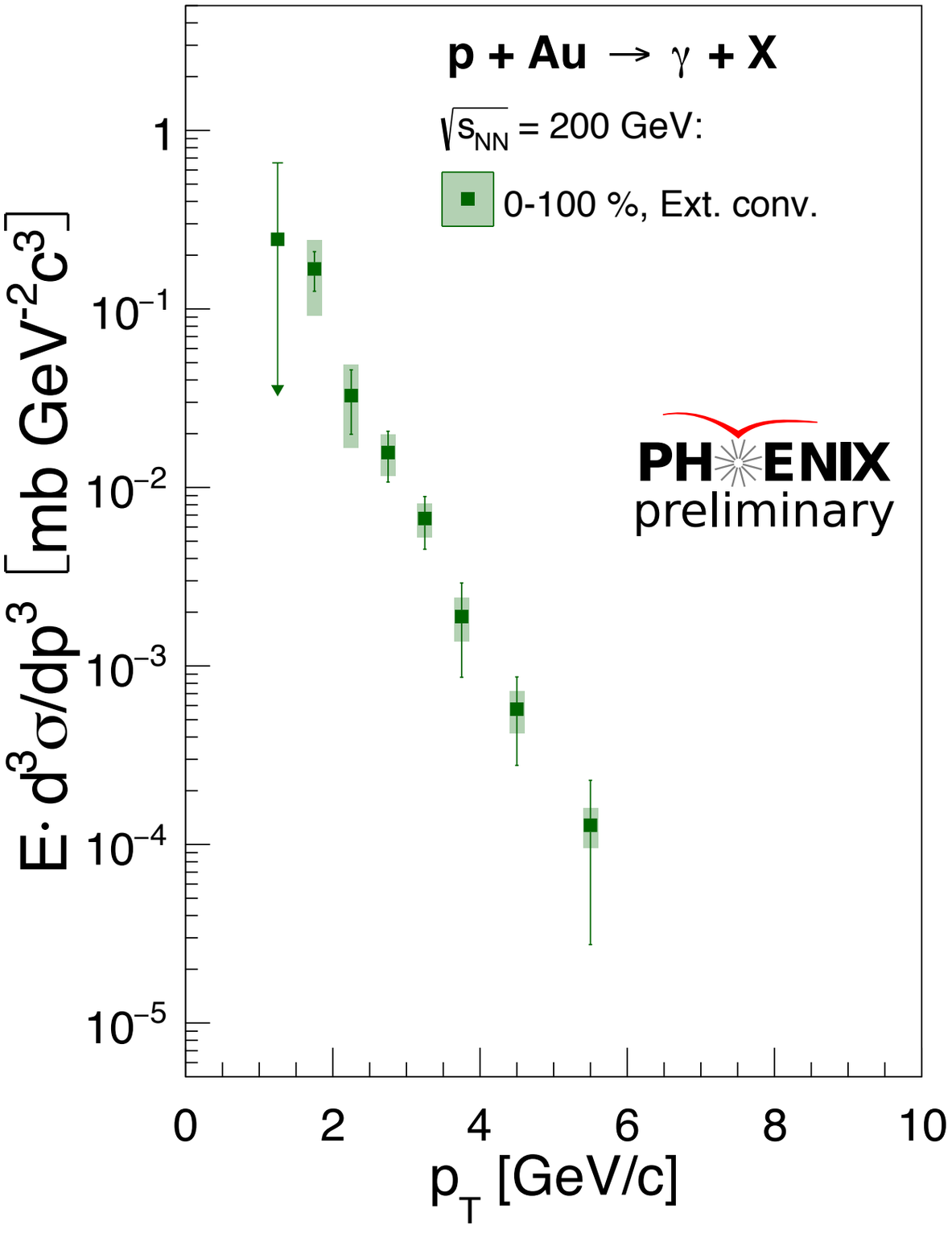
New result p+Au 200 GeV



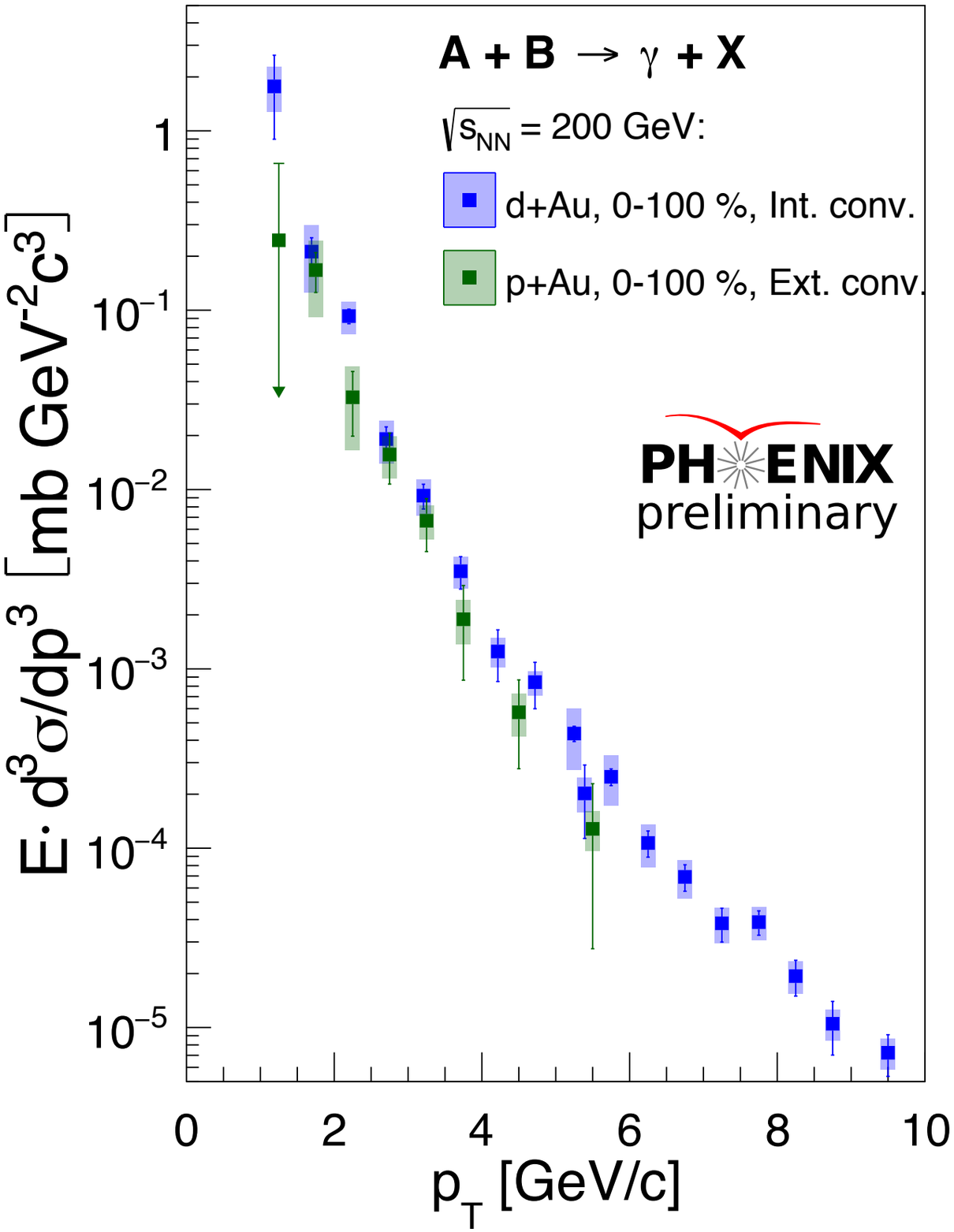
$$R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}} = \frac{\left\langle \varepsilon_\gamma f \right\rangle \left(\frac{N_\gamma^{incl}}{N_\gamma^{\pi^0 tag}} \right)_{Data}}{\left(\frac{\gamma^{hadron}}{\gamma^{\pi^0}} \right)_{Sim}}$$

$$\gamma^{direct} = (R_\gamma - 1)\,\gamma^{hadron}$$

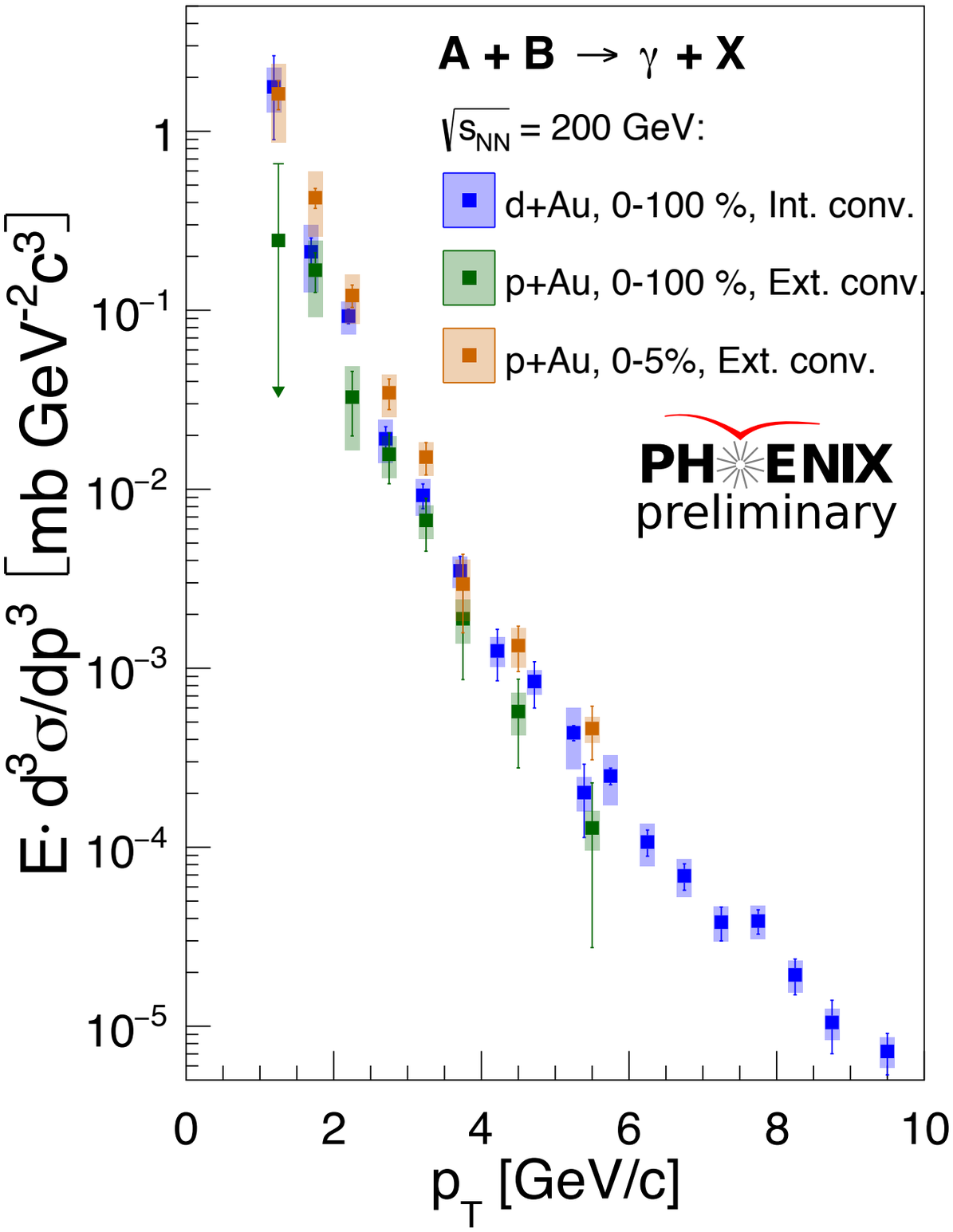
p+Au 200 GeV


p + Au → γ + X
√sNN = 200 GeV:
0-100 %, Ext. conv.
PHENIX
preliminary
E· d3σ/dp3 [mb GeV-2c3]
1
10−1
10−2
10−3
10−4
10−5
0
2
4
6
8
10
pT [GeV/c]

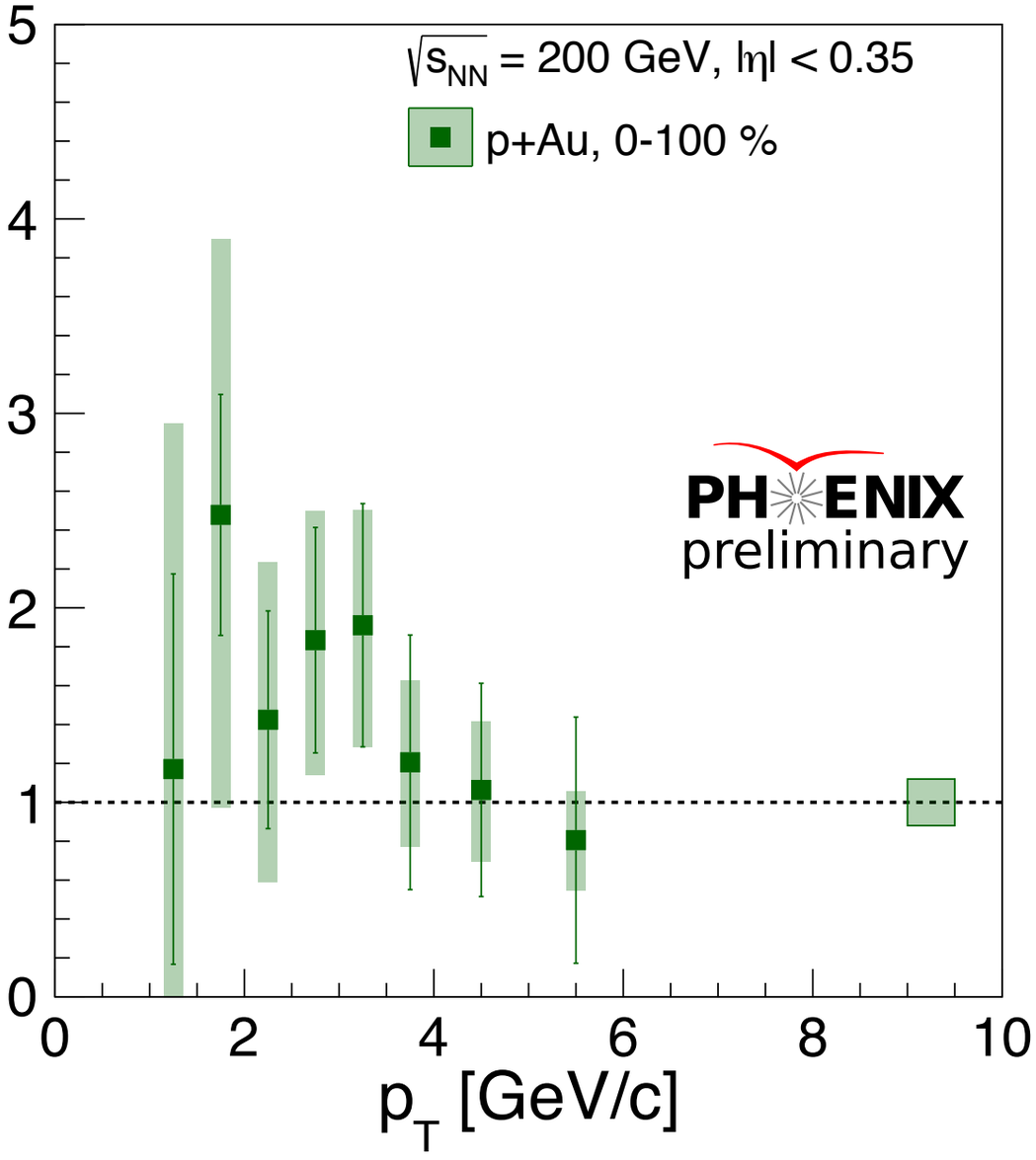
p+Au 200 GeV

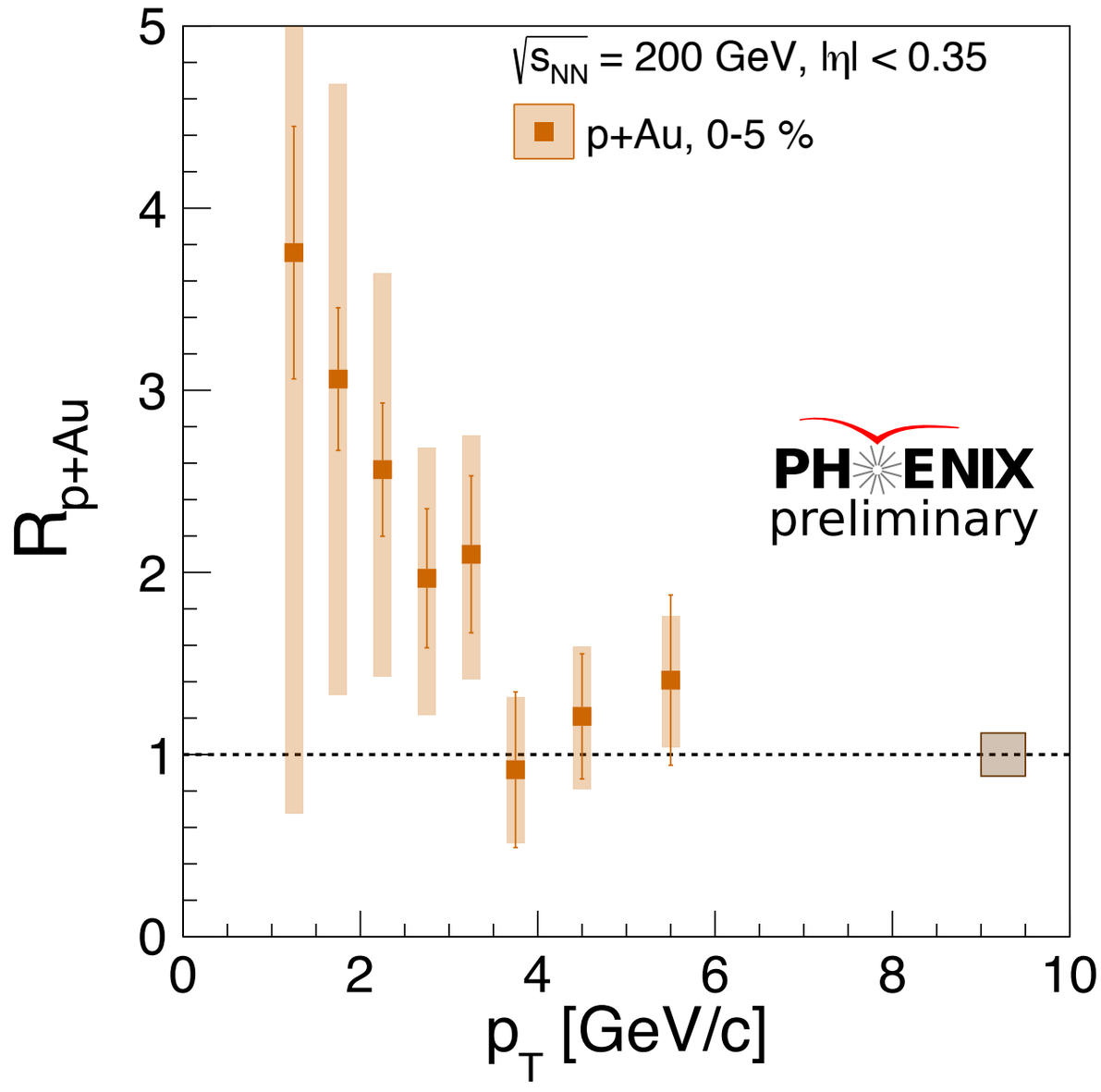

A + B → γ + X
√s_NN = 200 GeV:
d+Au, 0-100 %, Int. conv.
p+Au, 0-100 %, Ext. conv.
PHENIX
preliminary
E· d³σ/dp³ [mb GeV⁻²c³]
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
0
2
4
6
8
10
p_T [GeV/c]

p+Au 200 GeV


A + B → γ + X
√s_NN = 200 GeV:
d+Au, 0-100 %, Int. conv.
p+Au, 0-100 %, Ext. conv.
p+Au, 0-5%, Ext. conv.
PHENIX
preliminary
E· d³σ/dp³ [mb GeV⁻²c³]
p_T [GeV/c]
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
0
2
4
6
8
10

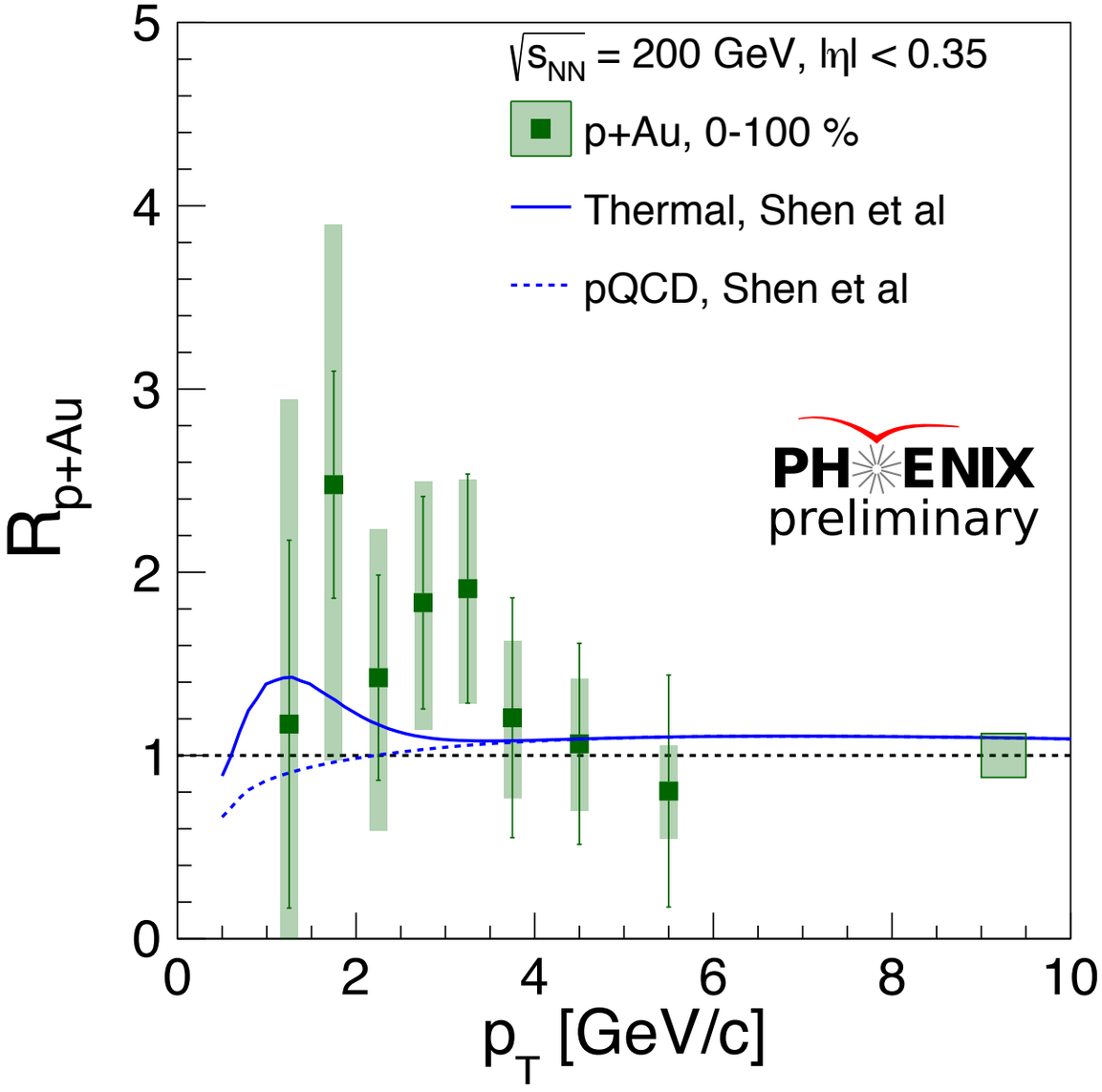
R_p+Au 200 GeV

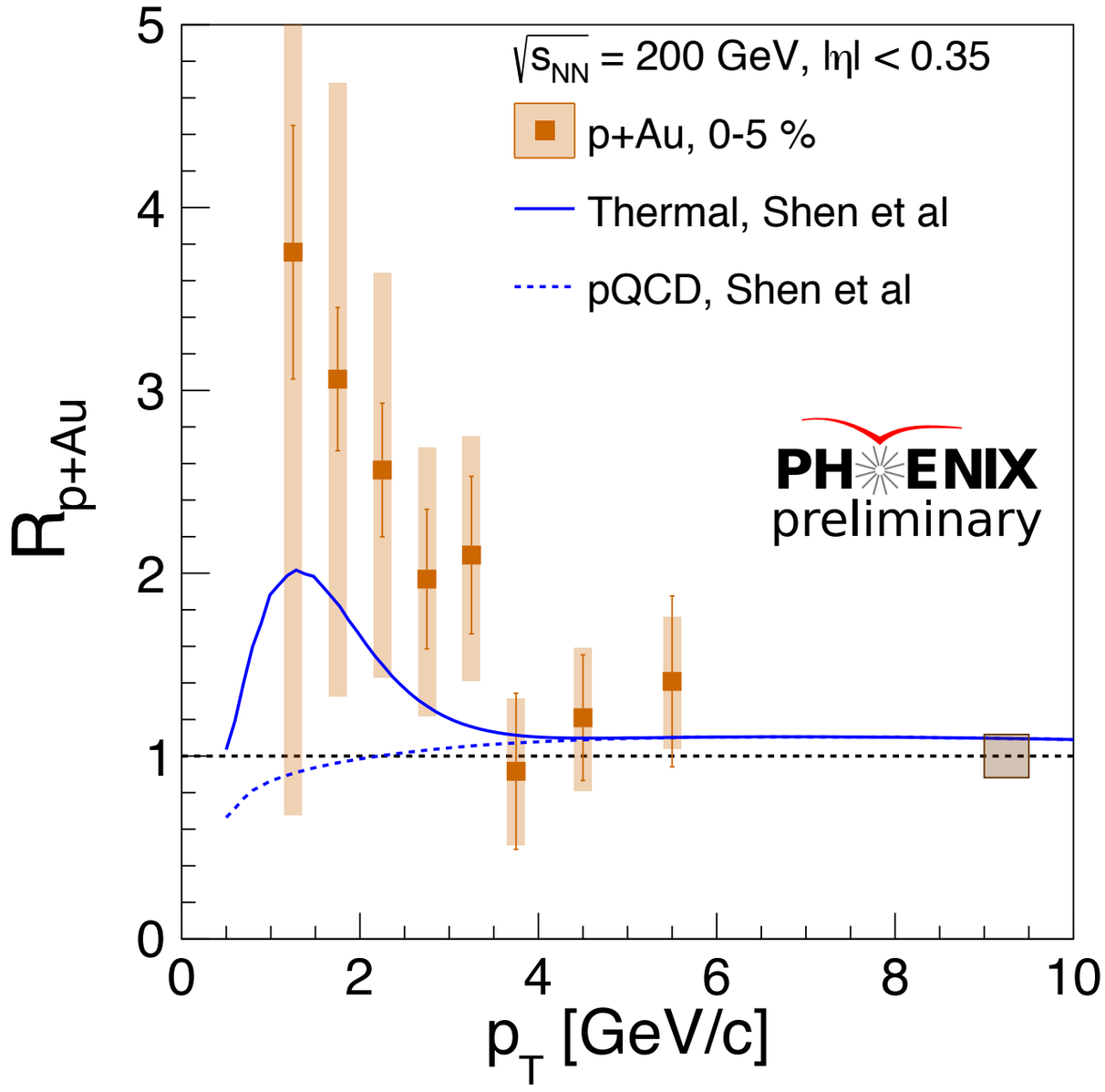




$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle N_{coll}\rangle d^2N^{pp}/dp_T d\eta}$$

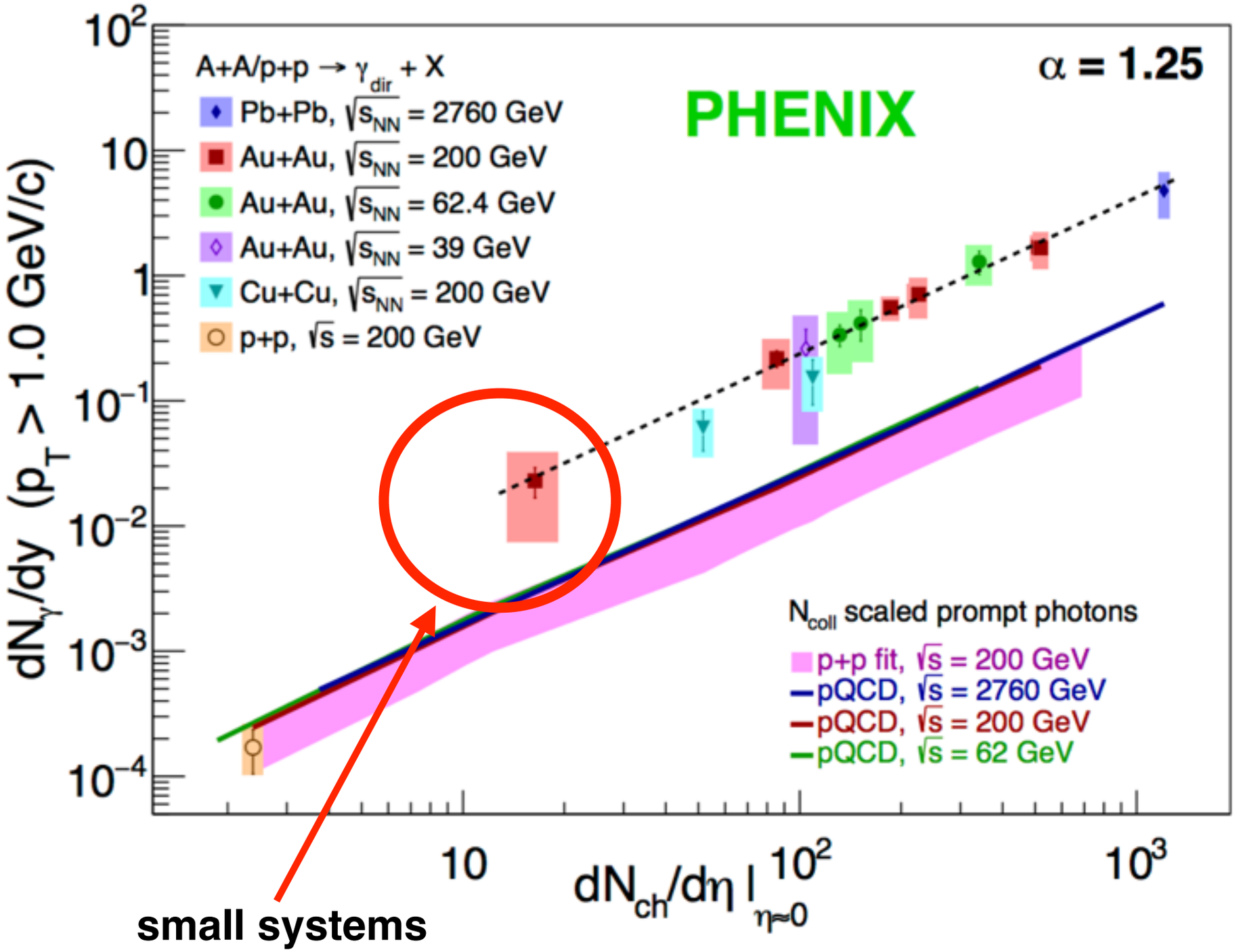
R_p+Au 200 GeV


$\sqrt{s_{NN}}$ = 200 GeV, |η| < 0.35
p+Au, 0-100 %
Thermal, Shen et al
pQCD, Shen et al
PHENIX
preliminary
R_{p+Au}
p_T [GeV/c]

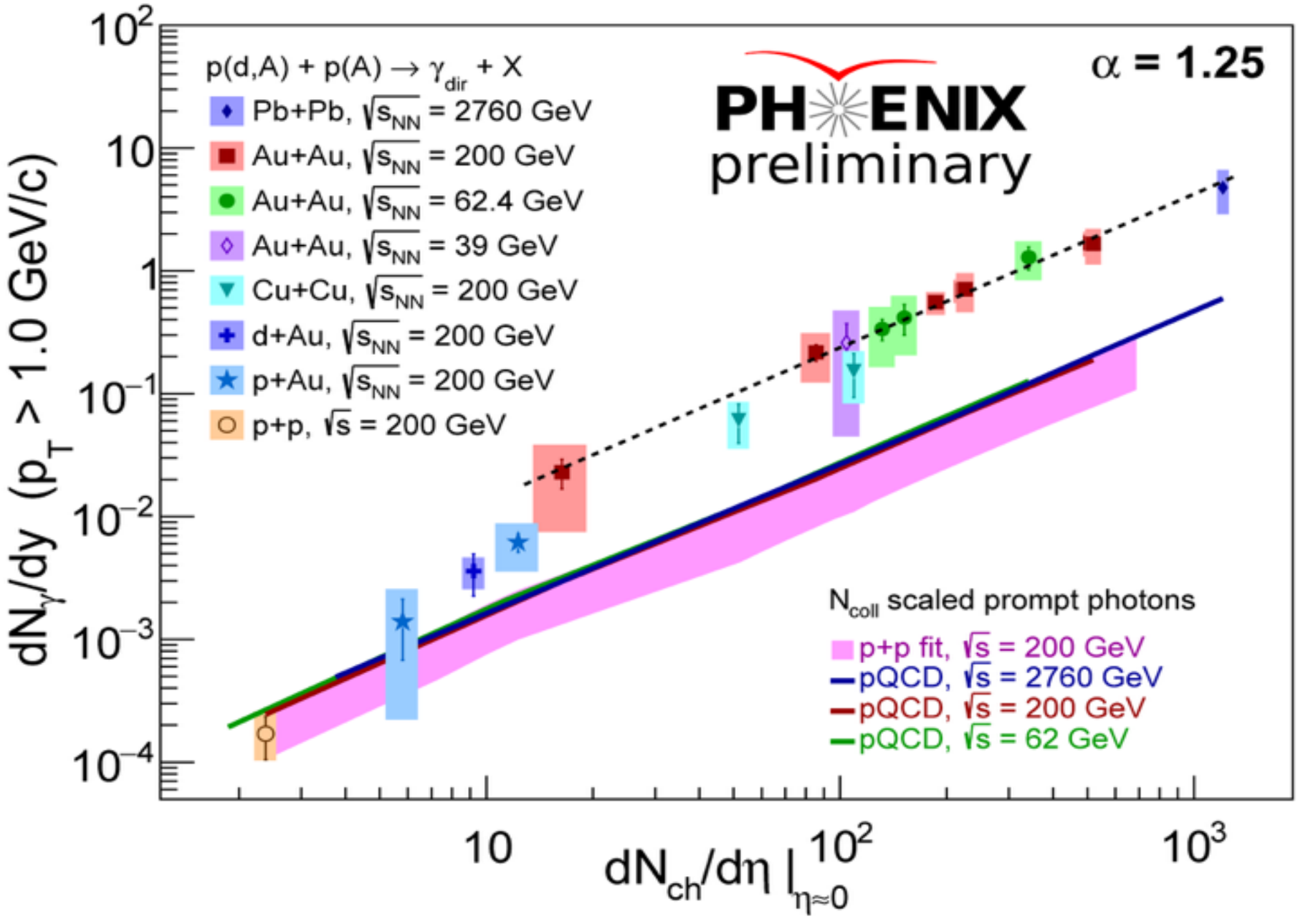

$\sqrt{s_{NN}}$ = 200 GeV, |η| < 0.35
p+Au, 0-5 %
Thermal, Shen et al
pQCD, Shen et al
PHENIX
preliminary
R_{p+Au}
p_T [GeV/c]

Direct photon scaling

arXiv:1805.04084



Small system and scaling

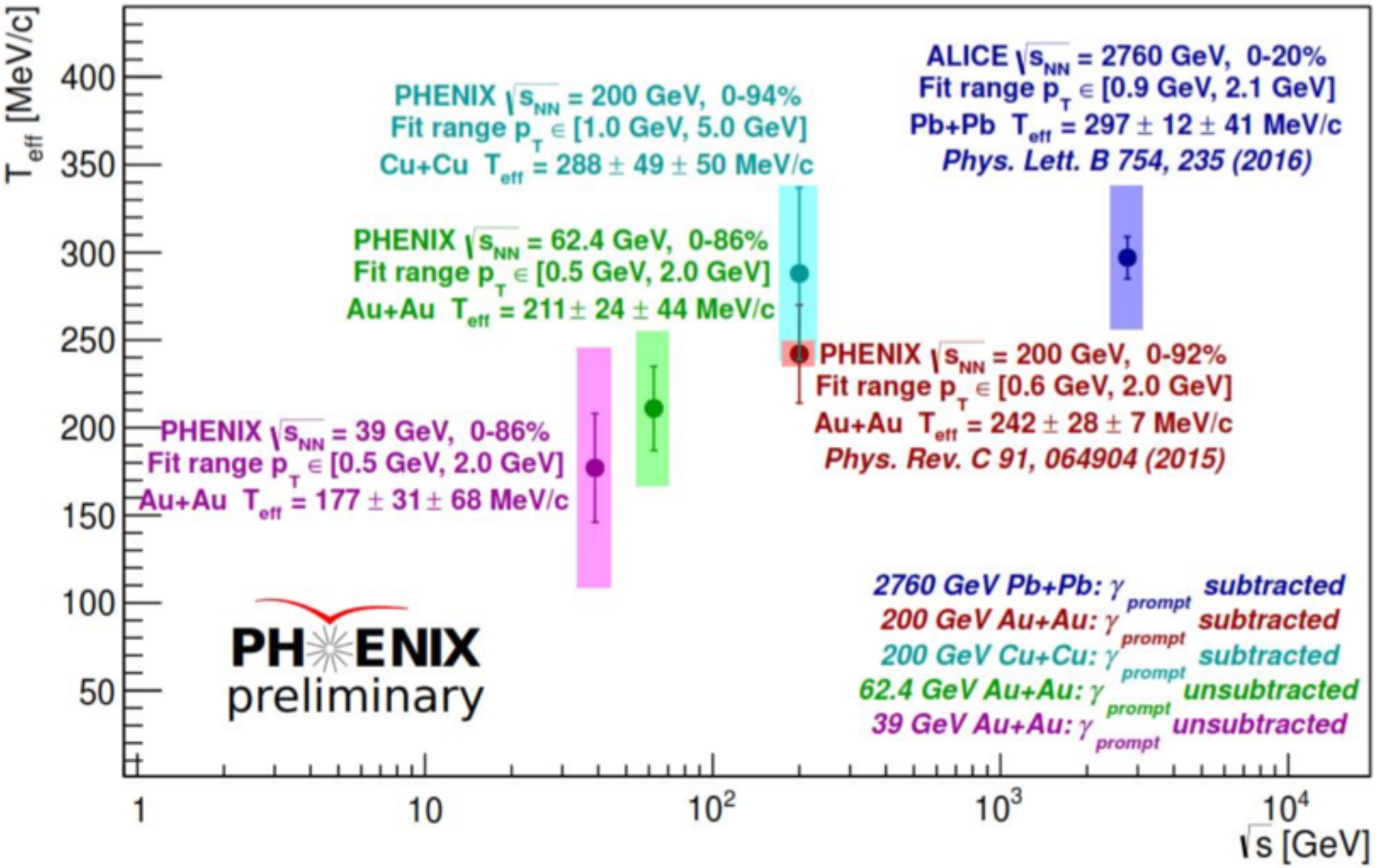


Summary and Outlook

- **Well established measurements of low p_T direct photons in Au+Au at 200 GeV :**
  - Large yield above expected in the low pT region
  - Large anisotropy v_2 observed for the direct photons
- **Theoretical picture still incomplete to describe large yield and v_2 simultaneously**
- **New results from Cu+Cu at 200 GeV,Au+Au at 62.4GeV & 39GeV and p+p,p+Au at 200 GeV**
- **Discovered a scaling behavior in large systems:**
  - Across energies N_{coll} is proportional to $(dN_{ch}/d\eta)^{1.25}$
  - At the same center of mass energy, low at high pT scale with N_{coll}
  - At all energies, low pT yield scale with $(dN_{ch}/d\eta)^{1.25}$
- **Measure a excess of direct photon in central p+Au at 200 GeV**
  - Data suggest transition from p+p to A+A like scaling
- **Future measurements from PHENIX :**
  - Search for direct photons in small systems: d+Au (2016) BES, ^{3}He+Au (2014)
  - High statistics (factor>10) Au+Au data from 2014 & 2016
  - Data from different collision geometry Cu+Au (2012)

Backup slides

T_{eff} vs Collision Energy



- Possible increase of T_{eff} with increasing beam energy